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WHAT SCIENCE REALLY MEANS

AN EXPLANATION OF THE HISTORY
AND EMPIRICAL METHOD
OF GENERAL SCIENCE

BY

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AND

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CONTENTS

WHAT SCIENCE REALLY MEANS

CHAPTER I

THE PROBLEM OF EMPIRICISM

Ulysses has no use for Plato, and the bones of his companions are strewn on many a reef and many an isle.

A. N. WHITEHEAD

UNDETERMINED MEANING OF SCIENCE

THE modern world, which has lost faith in so many causes, still accepts science nearly unchallenged. Science to-day occupies the position held by the Roman Church in the Middle Ages: as the single great authority in a world divided on almost every object of loyalty. The tremendous prestige which science enjoys is not undeserved. Yet despite the extent of its *réclame* and the wide reach of its practical effects, the genuine understanding of its purpose and method remains obscure. The banker and the barber share a conviction in the necessity for the continuance of scientific research, a conviction which far outruns their comprehension of what research consists of and what it hopes to accomplish.

Still more extraordinary is the fact that most of its practitioners, the scientists themselves, share this vagueness of what science is, or at best enlighten it with intuitive insight. It may seem a strange assertion that those

who lead a movement possess no clear idea of what they are doing, no definite conception of where they may expect it to lead. In short, there does not exist a single abstract formulation of scientific method on which all scientists agree.

Until the present, the successful procedure of science has only in a very limited sense been a matter of planning, and has often resulted from chance discovery and happy following of the correct method. Curiously, the early scientists who put physical science upon its right path did not have to understand fully the philosophy of science. Galileo, who led physics to its mathematical basis, professed to believe in atomistic mechanism. Newton, the great systematizer of physics, professed to disbelieve in the importance of general theory. Thus far this haphazard proceeding, with its cleavage between theory and practice, has not prevented profitable discoveries in the physical sciences, although it has led every other would-be scientific endeavour astray. The social studies have arrived nowhere as sciences because they have followed the explicit creed of physical science.

The time is over when scientific method can be followed without being explicitly understood. Not only will such innocence prove crucial, as it has done in all but the physical sciences, but it will also hinder and perhaps destroy the progress of physical science itself. The abstract understanding of a method may not be an absolute necessity at the beginning, but after a certain point it becomes indispensable for progress. Abstract understanding not only serves as a guide for those who have strayed from the true scientific method, but gives

reassurance to those who have intuitively anticipated it. Science, which has thus far blithely ignored definition, to-day finds itself under the necessity of being accurately defined.

CONFLICTING DEFINITIONS OF EMPIRICISM

All scientists agree that empiricism lies at the base of science, and some would even make the terms synonymous. Empiricism is the rock on which the scientific faith is built. Not only is this true of the physical sciences, but it is also true of those who would ape their method, and of those who wish to be 'scientific' in fields which are not yet reduced to the condition of science. Yet the very term which describes scientific labours is loosely used and remains as to definition largely a matter of disagreement.

What does empiricism mean? The following conflicting definitions, which have been drawn more or less at random, offer little satisfaction on this score. Aristotle employs the terms "empirical" and "historical" as having the same meaning. Sir William Hamilton states that "the term empirical means simply what belongs to or is the product of experience or observation." Whitehead offers this illuminating definition of empiricism, "that eternal objects tell no tales as to their ingressions." And Bridgman states the matter as follows: "empiricism . . . recognizes no *a priori* principles which determine or limit the possibilities of new experience."

These definitions, mostly by philosophers, paint a picture of confusion, and certainly do not define empiricism as it is understood by the scientists. On the other

hand, if there exists any single and unified definition of empiricism upon which scientists in general do agree, we have not been able to get them to tell us what it is. Clearly no scientist accepts in practice any of the philosophical definitions, since he is constantly dealing with what to him are empirical entities, which are not derived solely from sense experience. Metabolism, electromagnetic fields, ionization—these are empirical scientific entities, yet all are constructions of experience and none is altogether presented by mere sensation.

Whatever else the scientists mean by empiricism, they do not mean the limitation of all knowledge to sense experience, which philosophical empiricism involves. And the fact that they do not accept such a definition is evinced by their practice. Nevertheless, this confusion between philosophical and scientific empiricism may well result in disaster unless it is dissipated.

THE BIAS OF SCIENTISTS

Why has there been no abstract understanding securing full agreement concerning the aim and method of empirical science? The answer must be sought in the anti-metaphysical bias of the scientists themselves, a bias which arose at the end of the Middle Ages and which continues to colour the attitude of scientific men. The emphasis away from theory and toward the accumulation of indisputable facts of nature, to be learned by observation and experiment, precluded any possibility of speculation concerning true definition. Just as the Middle Ages appeared too metaphysical in their cloistered speculation, so the ages that followed went to the opposite extreme

and laid an implicit prohibition on all speculation. Scientists in fighting shy of metaphysics supposed that empiricism is not a philosophical affair at all. Their premises, though based on a metaphysics, were not understood as such, and since those premises were adequate for the development of natural science up to the end of the nineteenth century, the lack of interest in philosophy seemed to be pragmatically justified.

But the old materialistic mechanism which tried to present the world in purely tangible form, ruling out all else as mental interpretation, was a crude formulation. It had to postulate mysterious forces to work on tangible matter; it had to conceive so-called secondary qualities, such as colour, smell, etc., as unreal. Its very bedrock was a belief in an indestructible substance, a world of atoms each existing only by virtue of itself under various combinations. As a consequence, such combinations were not real in the same sense that the atoms were real, but merely combinations of real atoms producing different appearances. Nevertheless, such a belief was already contradicted by many of the facts of the old science. For instance, combinations of various atoms were tacitly admitted to make different 'substances' in chemistry. No chemist would have said that water and peroxide of hydrogen are two 'appearances' of real hydrogen and oxygen atoms. Thus tacitly it was accepted that differences in combination and organization were at least for purposes of manipulation realities. It is fair to conclude that even classical science dealt in non-sensuous entities as empirical.

However, at the end of the nineteenth century science

faced a crisis; it became questionable whether the scientists had succeeded in dodging interpretation as thoroughly as they believed they had. It seems strange that they could have overlooked the fact that the doctrine of exclusive reliance upon experiment is itself philosophical—no less philosophical for not being formulated as such. As has been shown time and again, the theory of empiricism is not itself empirically justifiable. Thus unconsciously scientists have fastened on to a contradictory theory: one that denies the validity of theory. Fortunately for the development of science, however, the practice has deviated from the theory. Had scientists been mere accumulators of facts, science would never have become the institutionalized search for truth that it is to-day. Even such an assiduous experimenter as the late Pavlov was, throughout his long career, advised young scientists not to let themselves "become the archivists of facts."[1]

The twentieth century brought about a new state of affairs. With the acceptance of the theories of relativity and quantum mechanics, the certitude resulting from the anti-metaphysical bias of scientists was upset. It became clear that the mechanical model of the universe which followed the Newtonian conception was no longer adequate to take account of all the fresh data. Physical scientists were unable to describe their subject-matter in picturable terms, and so were half led to accept the public estimation of science as a mysterious affair. Still reluctant to have recourse overtly to metaphysics, the scientists began to talk about first principles in terms of science, as though these were part of scientific findings.

[1] *Science*, vol. 83 (1936), p. 369.

And everyone concerned slowly had to admit that not only was science returning to philosophy, but also that it had never really abandoned it.

IDEALISM AND POSITIVISM

Now that science is driven back to search for its meaning in philosophy, two schools arise which attempt to define the first principles of science: idealism and positivism. Popular exponents of the first are Eddington, Jeans, and their followers. Their idealism, or perhaps as it is better described, mentalism, sets forth in effect that the physical world is a construction of the mind upon something ultimately unknowable, or that ultimate physical reality consists in mathematical thoughts in the mind of God, of which human beings know only the appearances. Such a subjectivism seems to cut the ground from under empiricism, or at best to make that doctrine psychological. Plainly, here is a conclusion that scientists refuse to accept. It has always been one of the tenets of scientific faith that objective agreement is essential to the development of science, and that such agreement must be kept free from any psychological opinion. "Mind-spinning" is just what the scientists have always been most suspicious of. And here is a philosophy which seems to assert that all scientific ideas are mind-spun.

The other school is that of positivism, which enjoys a new vogue partly because of its antagonism to the idealistic interpretation. This school, headed by Carnap, Bridgman, and others, represents the old scientific revulsion against metaphysics, though itself incurably metaphysical. Positivists claim that the reality of scientific

ideas rests solely upon their demonstrability in operation or experiment. They deny causality and substitute in its place the observation of the temporal sequence. Here is an attempt to escape subjectivism. But since its objectivism hangs entirely upon the sense experience and actions of the experimenters, it falls back into a subjectivism which makes scientific ideas mere shorthand summaries of experience.

The general tendency of the last decade has been to follow the positivistic rather than the idealistic interpretation of science. Scientists lean toward positivism for fear of wild and unrestrained theorizing. The attraction of positivism for scientists is that it seems to be hard-headed and practical, and to avoid metaphysical and mythological elements. It seems to draw a very sharp dividing line between what is scientific and what is not. This bias should not surprise anyone familiar with the history of science; nevertheless it is as wrong-headed as idealism. That, in fact, positivism suffers from the same defect as idealism will be shown later.

REJECTION OF BOTH THEORIES

There are many objections which will immediately appeal to anyone who considers science according to the doctrines of idealism or positivism. The exact contentions will be examined in later chapters. At present we may briefly group a few arguments to show how dubious these positions are.

Is empirical science, which has always prided itself on being objective, in that it allows no one man's opinion merely by being an opinion to alter the facts, now going

to assume that the only objective basis can be opinion? Can science be what Bridgman calls it, "my private science,"[2] and remain science? In other words, is science to be reduced to a psychological matter of consciousness? Does anyone truly believe that the application of mathematical laws to nature is mental? In other words, do they work because we know of them, or do we not rather know of them because they work? Did iron assume magnetic properties simultaneously with the discovery of its magnetic properties?

If we grant the idealist's contention that the photoelectric cell and the Wilson cloud chamber are equally mental, how can the differences between them be accounted for? Certainly this difference will have to be explained in non-psychological terms. Therefore the scientific problem from the idealist point of view remains just what it was before. To place the observer within the field of that which he observes is like making a camera an essential part of every picture of Niagara Falls. The idealist philosophy is plainly no answer to the much sought-for philosophy of empirical science, and the scientists are right in their intuitively arrived at decision to refuse it.

The objections to positivism are equally cogent. Whatever else empirical science may be, it is certainly not positivistic. If it were, new empirical entities would never come to light, since everything not already discovered would remain a theoretical hypothesis. Thus science could never have advanced. But ignoring this, let us inquire in what way are electrons summaries of

[2] *The Nature of Physical Theory*, p. 13.

anybody's experience? Are Kepler's laws of planetary motion and Balmer's law for the position of lines in the hydrogen spectrum altogether products of experience? The whole applicability of mathematical science would be negated if scientific laws were merely summaries of past happenings. Positivism overlooks the most obvious ambition of science: the aim to reach exact predictability.

The procedure of science toward the successful unification of physical theory, as when gravitation and inertia were enveloped by the theory of relativity, should indicate that laws cannot be merely statistical summaries, and that something more than a mental unification of experiments is being reached. The grave objections to positivism are enough to suggest that positivism is not the required answer to the newly recovered need for a philosophy of science. Positivism is more of a danger to the future of science than idealism because the former has secured more support from the scientists than its rival, and indeed just now seems to be the choice wherever scientific men feel the need for a philosophy. What the positivists have done is to hold on to experimentation, and thus as they see it to empiricism, at the cost of denying reality to the scientific subject-matter itself. They have saved the method only by sacrificing the existence of that which the method studies.

In idealism and positivism there is no objective reality to the entities of science. Neither idealism, which would refer science to the psychology of consciousness, nor positivism, which would refer it to the psychology of behaviourism, is adequate to supply an understanding of

what empirical science is. The first theory dissolves empiricism; the second tries to hold on to it by dissolving everything else.

SCIENCE AND THE PUBLIC

The prestige of science is very great even outside scientific circles. Thus far the public has not looked to science altogether in vain. The tremendous hope invested in science is amply justified at least by the physical sciences, although to be sure this does not mean that the public understands what science is or what it is trying to do. Rather does the layman look to science to announce what reality is. Thus it is not too much to say that whichever way the interpretation of science turns the popular understanding of reality will follow. Obviously, then, what has been said about the bias of the scientists in favour of positivism applies with equal force to the public. To the popular mind science is an agglutinative compendium of facts largely unrelated.

The form which popular positivism assumes is that of placing great faith in seemingly demonstrated facts and of distrusting all theory. Its assumption that this procedure is the scientific method is well shown by the constant appeals in the popular Press, in advertisements, and in innumerable arguments where the terms 'science' and 'scientific' are bandied about as conclusive and irrefutable. The fact that the public accepts the contradictory beliefs that science is altogether concerned with final and utterly demonstrable matters of fact, and that science is always in process of changing its mind, only goes to reinforce the statement that the public knows

no explicit formulation of science but implicitly accepts positivism.

The question may be asked as to what difference it makes whether the public understands science or not, particularly in view of the fact that science has gone forward without public understanding. It is true that physical scientists have been able to proceed until now unmolested, carrying through a rational programme within a society which still tries to go on in the old irrational manner. But it is already becoming obvious to many thoughtful scientists that this condition cannot continue indefinitely. We may say that the historical career of physical science has so far been promoted by good luck. Already, however, there are signs that the rear-guard is deserting the scientific vanguard, and that science is too far ahead of the main procession of humanity and may soon be cut off from the service of supplies. For this not to occur, it will be necessary for the public to understand at least a little of the aim and methods of science. In other words, the public must recognize the value of theoretical science as well as the usefulness of applied science.

If some such understanding of science does not reach the public, it will no longer continue to have patience with anything but immediately practical results. Need it be urged that practical results do not come without a theoretical background? Continued ignorance on the part of the layman may have the social effect of abating the development of theoretical science. Thus the clarification of science and scientific method is much more than a philosopher's idle speculation, or a theory spun

to satisfy the desire of a few specialists to understand what they are doing. The need for an understanding and clarification of empirical science is not only a practical necessity for science proper, but also one for the world in general. Science and the public benefit together, or neither benefits.

PURPOSE OF THE BOOK

We believe it can be shown that the subject-matter of science has existence with or without its comprehension by the mind, with or without the experiments by which it is demonstrated. If empiricism can be shown to have reference to an independent system which men can discover and follow, but which they do not create either by conceiving it or by performing certain operations, then scientists need be in no doubt as to the objective reality of their entities. In other words, a proper understanding of empiricism would exhibit that the so-called 'concepts' of science refer to entities which are not concepts and not operations but independent facts. The critical misunderstanding of reality as applying only to tangible things is responsible for these two variants of mentalism: idealism and positivism. The functions which scientists analyse can hardly be called tangible or sensory, though observable only in and through things and events as processes. Empirical science needs further philosophical exposition.

The main requirement, then, is the definition of the aim and method of science, which in turn involves the clarification of empiricism. The stubborn and intuitive understanding that empiricism must at all costs be pre-

served is a virtue of the physical scientists' practice. But for this intuition to be rationally justified requires something more than mere faith. It deserves an explicit creed. The utter exclusion from metaphysics in which science thus far has tried to hold itself has been invaded, and ostrich tactics will not avail.

In analysing empirical science as to its aim and method, we do not claim the discovery of anything new. On the contrary, we are trying to abstract and make clear what that aim and method have always been, what they should be, and what they must be. In so far as science has succeeded during its historical career, it has followed a certain method. Therefore we are not concerned with the way in which it has proceeded historically, except in so far as such an inquiry helps us to learn the way in which it should proceed logically. The fact of the manner in which scientists have stumbled upon or deliberately reasoned their way to the truth must be distinguished from the ideal toward which they have aspired only by approximation. Whether a child learns arithmetic by counting on his fingers or his toes has no effect upon the cardinal number series with which he becomes familiar. But obviously it is preferable to proceed logically, if only because such procedure saves time and energy. The ideal method of science is not of necessity the exact one followed by any scientist.

What we are claiming, then, for the clarification of the aim and method of empirical science is that whatever procedure the scientist may take to arrive at new hypotheses and new facts, he will be able to understand far better what he is doing; and in the long run this will

unquestionably keep him from wandering too far afield, as it will also set his inquiry into fruitful paths. In a word, what he has been accomplishing mainly by intuition and incomplete understanding should be available to him as an abstract formulation.

CHAPTER II

THE ORIGINS OF EMPIRICISM

It is an unwarranted assumption that ancient science differed in principle at any point from that of to-day.

W. A. HEIDEL

IN order to understand the place which empiricism holds in the esteem of scientists, as well as to expose the cause of the antagonism of science to the speculative reason, it will be necessary to give a short sketch of the history of empirical science. Only history can show how scientists could have made the error of absolutely dividing the empirical from the logical. However, no attempt is made here to sketch an adequate history of science; all we can hope to accomplish in so short a space is to exhibit the occasion for the rise of empiricism and to touch on the significant points of its development.

HELLENIC EMPIRICISM

The history of empirical science is at least as old as recorded cultural history. In Egypt and Babylonia the beginnings of the sciences of astronomy, medicine, and mechanics were due to speculations upon problems of a practical nature. It was necessary to make careful observations and to draw inferences from them. But of course this early empiricism was neither formulated as a theory nor segregated as a practice, but was resorted to along with magic, astrology, and other pseudo-sciences.

Early Greek empiricism was of this same sort, although the Greek nature philosophers were more inclined to be sceptical in regard to mythological and magical explanations. Thales' belief that water is the prime substance was an induction which went beyond the verifiable facts, yet it was based on the empirical observation of the presence of moisture in natural objects. Thales experimented in other matters, as when he showed that amber rubbed would attract light bodies.

The statement that the Greeks were not empiricists but relied exclusively on reasoning is not true. Anaximander observed that the heavens revolve around the pole star. And although the name of Pythagoras is associated with mystic sciences, such as numerology, he is said to have accomplished one of the finest pieces of observation and inductive reasoning, which he afterwards deductively checked. Noting that the sound of two hammers on an anvil were separated by an octave, he weighed the hammers to find that the weight of the one was double the weight of the other. This experiment was then repeated on the monochord, from which it was found that the length of string was likewise proportional. The length of string required to produce the concordant notes showed the proportions 12 : 8 : 6.

Alcmaeon of Crotona, a younger contemporary of Pythagoras, was likewise an experimenter. He dissected animals; discovered the optic nerve; distinguished empty veins from those carrying blood, etc. Xenophanes of Colophon gave the correct interpretation of fossils. Anaxagoras dissected the brain and recognized its lateral ventricles; he discovered that fishes breathe through their

gills. The Hippocratic Corpus is filled with all sorts of examples of careful and minute observation. For instance, embryology was studied by opening hen's eggs day by day as incubation progressed. Euryphion of Cnidos, among other experimental researches, discovered that pleurisy is a lung affection. Eudoxus of Cnidos experimented in astronomy, acoustics, mechanics. Philip of Opus explained the rainbow as a phenomenon of refraction. The observations of Aristotle in zoology are famous; e.g. his description of the placental development of the dogfish, and of the stomach of ruminants. Aristoxenus and Strato, both members of the Aristotelian school, conducted rigorous empirical observations in the physical field.

Enough has been said to show that the Greeks observed as well as speculated. But if experimentation was as plentiful as our random examples indicate, why was Greek science not more fruitful? The reason for the failure of Greek science is that observation by itself, like speculation by itself, is not sufficient for science. The Greeks, it is true, both experimented and speculated, but theory and experiment were kept too far apart. Thus their experimentation became positivistic and their reasoning dogmatic. Aristotle exhibits both errors. At times he is an empirical dogmatist (positivist), as when he is certain that plants cannot feel "because they are composed of earth."[1] and at other times he is a rational dogmatist, as when he asserts that just as "the triangle is implied by the quadrilateral," so "the nutritive faculty [is implied] by the sensitive."[2]

[1] *On the Soul*, III, xiii. [2] Ibid., II, iii.

It must be admitted that the general tendency of Greek thought militated against the development of empiricism as a creed. Unfortunately for the progress of empiricism, Greek philosophy in its thorough grasp of the place of reason, held experimentation back. There was a prejudice in the Greek mind in favour of discovery by deduction from principles held, instead of discovery by induction from experiment. The world of actuality was derogated in the Platonic version to a mere appearance of a divine order of Ideas. And thus an intellectual demeaned himself somewhat by abandoning pure thought for vulgar experimentation. "Science," said Aristotle, "should concern itself with eternal objects immutable and pure." Socrates asserted that the subject-matter of physics is "vain, useless and perilous."

This whole attitude unquestionably held back science, even though remarkable beginnings show the wide interest of the Greeks in empiricism. "Theory and practice do not always progress *pari passu*,"[3] and the Greeks understood at least the difference between how science progresses and how it should progress.[4] Greek theory and practice, however, broke away from each other, and when Greek science was carried into Christian Europe, it was the dogmatic categorization and reliance on deductions from unproved assumptions which were preserved; its empirical basis was forgotten. The bias of this heritage should be carefully noted, because it was the revulsion against the dogmatic aspect of Greek science which led the early empiricists of Latindom to

[3] W. A. Heidel, *The Heroic Age of Science*, p. 95.

[4] Hippocrates, *De Prisca Medicina*, 12 (III, 596 f., L).

rediscover empiricism, but with the difference of opposing it to the speculative reason.

HELLENISTIC EMPIRICISM

Aristotle died in 322 B.C., and the Hellenistic Age of Greek expansion which followed saw a greater development of the practice of empiricism. Despite the weight of Aristotle's authority this new age was to distinguish itself principally in experimental science. Why was empiricism more widely practised in the civilization which centred around Alexandria than in the one which centred around Athens? While it is undeniable that the new era had a respect approaching awe for the older Greeks, it is also true that this very fact made the Hellenistic Greeks commentators and analysers rather than innovators. In literature this produced grammarians and rhetoricians, but in the study of natural objects it brought about the beginnings of a thoroughgoing science by focusing attention on analysis, and *a fortiori* on experiment. Moreover, Aristotle had excluded the mathematical method from philosophy, and as a consequence it went by default to science. This isolation of science from philosophy proved *pro tem.* a good thing, though in the end it corrupted both. Philosophy became more concerned with the unearthly and the mystical, and science became more positivistic.

But in the beginning of this period the return of science from remote contemplation to practical research proved fecund. Theophrastus of Lesbos wrote describing minerals and plants, of which he certainly had experimental knowledge. Dicaearchus of Messina noted the

influence of the sun upon the tides. Herophilus and Erasistratus rejected all references to the occult and insisted upon natural causes. They practised dissection and, it is said, vivisection, thus improving enormously the knowledge of such organs and functions as liver, salivary glands, brain, the relation of vascular to nervous systems, and the relation of respiratory to arterial systems. Aristarchus of Samos, who arrived at a heliocentric theory, worked the results of his observations into geometrical form. Note the difference between the use of mathematics here and in Plato's astronomy: the first is based on reasoning from observation of what is, the second on reasoning from what (it seemed) ought to be. Eratosthenes' famous experiment in calculating the size of the earth by actual observation of the latitudes and distances of Syene and Meroe failed only by fifty miles of the true value of the diameter.

Archimedes was the greatest Hellenistic scientist and one of the foremost experimental scientists of all times. He had, moreover, a clear abstract understanding of scientific method. He wrote:

> Certain things first became clear to me by a mechanical [i.e. experimental] method, although they had to be demonstrated by geometry afterwards because their investigation by the said method did not furnish an actual demonstration.[5]

Accordingly, he weighed mechanical models of the parabola and ellipse, demonstrating the result by the geometrical method of limits, and finally generalizing this method to an anticipation of the integral calculus.

[5] Cited in Heidel, *The Heroic Age of Science*, p. 101.

It is not true that Archimedes' procedure differed from that employed by modern science. For example, in his work on floating bodies, starting from the observation that water has the geometric property of being fluid in all its parts, he proceeded deductively to the conclusion that a solid heavier than water will lose its weight in water, a weight exactly equal to the weight of the water displaced. This he verified experimentally, and thus established the principle of specific gravity. Of course, the train of reasoning might have been different. A scientist of to-day might note through various experiments the weight of the displacement of a body, and leap to the induction that the weight of the body is equal to the weight of the water displaced. He might then formulate the principle mathematically. Both procedures, however, are equally empirical, equally deductive and inductive.

Mystic neo-Pythagoreanism continued, but scientific mathematics was also well under way by this time. The name of Euclid needs no comment; but it is not so well known that beside being a geometer he also worked on optics, discovering the propagation of light in straight lines, and the laws of reflection. Apollonius of Perga was the same type of mathematical scientist. The significance of his work was not so much the discovery of the properties of the parabola, ellipse, and hyperbola, but in generalizing these as sections of one cone, and thus in beginning projective geometry.

The understanding of Hellenistic science as hopelessly theoretical is without foundation. Indeed, we have been attempting to show that its direction was the opposite,

and that it too soon became 'practical' and positivistic. Philo of Byzantium, though a mathematician, is chiefly known as the author of an encyclopaedia of applied mechanics, and for his work on pneumatic machines. Likewise Hipparchus, though a mathematician, is mainly notable as an inventor of astronomical instruments, and for his rejection of the heliocentric system as too theoretical. The same practical turn is to be seen in Hero, who was almost entirely concerned with the applications of mathematics and mechanics, and who contrived many machines, e.g. siphons, steam engines, and fire engines; Hero's *Pneumatics* was almost a laboratory manual.[6]

The growing interest in a positivistic point of view and the narrow practicality of the late Hellenistic Age are manifest in the next group of scientists we have to consider. Strabo, Seneca, and Pliny the Elder wrote vast compendia of knowledge. Vitruvius and Frontinus did, it is true, make contributions of a scientific nature, but these were chiefly practical devices which bore narrowly on their own work. Frontinus wrote on hydrodynamics in connection with the engineering of the aqueducts, and Vitruvius contributed as an architect to acoustics, and, as superintendent of military engines, to ballistics. Celsus and Dioscorides were both medical encyclopaedists, notable recorders, but cautious theorists.

The Alexandrian period comes to an end with two colossal figures, Galen and Ptolemy. With them the positivistic progress of Hellenistic science reached its culmination. Although Aretaeus, Galen's contemporary, was a greater physician than Galen, it was the latter's

[6] Heidel, op. cit., p. 191.

dogmatic and systematic summary which won him the most acclaim.

His chief merit consists in having systematized and unified Greek anatomical and medical knowledge and practice.[7]

Although Galen did experimental work, e.g. on the sensory and motor nerves, his chief historical importance consists in the fact that he closed inquiry rather than opened it.

Ptolemy played the same role in astronomy that Galen did in medicine: he systematized the science on positivistic lines. Note the common-sense empirical argument of Ptolemy against the movement of the earth: that if the earth were moving a bird on the wing would soon be left behind. Herein is indicated the abandonment of the attempt of Aristarchus to formulate astronomy in theoretical terms which go beyond the appearances of common sense. However, the Ptolemaic system was an improvement in economy over the older and more awkward crystalline spheres. The Ptolemaic system of cycles and epicycles is a summary of observations, and like all such summaries does not suggest any new conclusions, and was "primarily a bookkeeping device."[8] When such an ideal of science is adopted, it is the end and not the beginning of speculation. This alone should make the scientists beware of accepting the positivistic version of empiricism.

The failure of late classical science to perpetuate itself has a simple explanation. Its separation from abstract

[7] George Sarton, *Introduction to the History of Science*, vol. i, p. 301 ff.

[8] Benjamin Ginzburg, *The Adventure of Science*, p. 68.

speculation rendered it cautious and down-to-earth, to the extent of becoming more and more concerned with special practical problems and summaries of past work, until it died of positivism. Abstract speculation divorced from science fled to philosophy, there to concern itself altogether with ultimate problems of ontology. To separate science and philosophy is hurtful to both. It leaves philosophy without ground under its feet and hence in the eerie realms of mysticism; it leaves science flat on the ground, tied to the impotence of positivism. This extreme is as harmful to science as is the wild theorizing of a Plato, and curiously enough both result in pesudo-empirical sciences like alchemy and astrology. For, be it noted, the astrologists and the alchemists were of all 'scientists' the most practical in ambition and the most experimental in procedure—however null the result. In this nadir of scientific research the great flowering of science was lost to the Hellenistic world—to be resumed elsewhere.

BYZANTINE-MOSLEM EMPIRICISM

It is generally believed that after Hellenistic science died out, there was a period of perhaps four centuries when the whole tradition of experimental science was dead, and that it lay dead until Moslem culture resurrected it. There is no foundation for this view. The truth is that science shows a continuity from the ancient Greeks to the modern scientists; and there was never a period when science was abandoned altogether everywhere. After the decline of the Hellenistic Age, empirical science was preserved in the Byzantine Empire. While it is true that

there were no great Byzantine scientists, that the Byzantine scientists added little to the tradition, still they did serve the valuable function of keeping it alive.

Oribasius, the last of the true Hellenistic scientists, flourished about A.D. 370. He wrote a medical encyclopaedia in seventy books, and fought the growing superstition of the age. But there is no real break between him and Proclus. Proclus may be termed one of the first of the Byzantines. He worked in astronomy, describing the method of measuring the apparent diameter of the sun by means of Hero's water-clock. In mathematics he worked particularly on the properties of certain higher curves. Martin Capella, generally known as a Christian theologian, set forth an explanation of the hemi-heliocentric system, and discussed geometry and arithmetic. Anthemius (*fl. circa* 510) was a practical mechanic and mathematician. He was employed in the reconstruction of the Cathedral of St. Sophia, but he also wrote theoretical treatises on the parabola, and on the properties of burning-glasses. His contemporary, Philiponus, was a scientist in the best sense of the word. He disproved Aristotle's law of falling bodies experimentally; denied the Aristotelian theory of the impossibility of a vacuum; and described astronomical instruments, especially the astrolabe. It is not difficult to see that there is no qualitative difference between this kind of scientist and those of the late Hellenistic Age. These names must be considered a mere indication of the extent of experimental science. For instance, Bishop Synesius of Ptolemais requested Hypatia to procure for him some

baryllium to make an hydrometer, proving that the instrument was well known at the time.

Justinian, who closed the philosophical schools of Athens, opened one of his own devoted to the study of mathematics in 532. The seventh century contained besides physicists many medical scientists. Alexander of Tralles, Theophilus Protospatharius, Stephanus of Alexandria, Stephanus of Athens, Aaron of Alexandria, Paul of Aegina, all were eminent doctors who wrote on the theoretical side of medicine.

Although Byzantine science suffered a decline after the seventh century it never entirely disappeared, and in the ninth and tenth centuries underwent a renaissance. Leon of Thessalonica was a notable figure in this period. However, it was in the seventh century that Byzantine science reached its height and began to influence the countries further east, preserving the continuity between Byzantium and Islam. Severus of Sebokht was a Christian bishop who started a school of Greek learning in Western Syria about 650. He added to the Greek scientific tradition the use of Hindu numerals; without them the high modern development of science would have been impossible.

Towards the beginning of the Byzantine period (489) Nestorian Christians emigrated to Edessa. They were dispersed further east by religious persecution and transferred to Ctesiphon, and in 762 they again transferred to Baghdad. They were the principal agents by which Greek science and learning were introduced to the Moslem world. Therefore there is no hiatus between Byzantine and Moslem science. It is notable that Baghdad

became the great centre of Moslem culture after the Nestorians had settled there.

The first Moslem scientists were mainly encyclopaedists and translators. Al-Fazari, who flourished late in the eighth century, translated Sanscrit works and thereby introduced Hindu numerals to the Moslem world. This is the great advantage which Moslem science held over Byzantine. Moslem science, however, had still to free itself from pseudo-science, and in the works of Jabir we can already see signs of chemistry emerging from alchemy. Early in the following century Al-Quarizmi, syncretizing Greek and Hindu science, developed mathematics, particularly algebra, far beyond anything that either Greek or Hindu alone had accomplished. Al-Kindi and Al-Farghani made translations from the Greek, and the latter as an astronomer following Ptolemaic theory wrote on celestial motions. Ibn-Qurra illustrates again the great reliance on Greek sources; he translated Apollonius, Archimedes, Euclid, and Ptolemy into Arabic.

At the beginning of the tenth century Moslem science had absorbed sufficient influences to become experimental on its own account, and its learned men attempted to treat of all fields of knowledge. Al-Razi was an important physician who combined his knowledge of chemistry with medical practice. He was much more than a mere syncretizer of Greek and Hindu medical knowledge, being an experimental chemist, physician, and physicist (hydrostatics). Al-Battani was an astronomical scientist who combined theory with observations; he discovered the motion of the solar apsides, and in his trigonometry employed sines instead of Greek chords. To correct the

erroneous impression that Moslem science was confined to mathematics and the natural science, we have only to mention Al-Farabi, who wrote on psychology and social science, e.g. a work entitled *The Model City*, in which city planning is discussed. This same scientist also dealt with the theory of music and the theory of science in general. Al-Sufi was another observational astronomer, who made the most complete map of the fixed stars. So many are the Moslem scientists that the work in any one branch would be astonishing. In mathematics alone it is impossible even to give a list of all those who contributed.

The scientist Al-Hazen made most important contributions to the study of optics, explaining atmospheric refraction, the apparent increase in the size of the sun when on the horizon (twilight phenomena), also the theory of lenses. He was strictly an experimental scientist who neither in method nor practice differs from the best of any period.

Two great figures dominate the close of Arabic scientific genius: Avicenna and Al-Biruni. Both were systematizers and summarizers of all that went before. Though experimenters, they are chiefly remembered for encyclopaedias of existing knowledge, which, because of their completeness, unfortunately helped to sterilize Moslem science. Al-Biruni made geodetic measurements, contributed to geology, surmised the rotation of the earth on its axis. He was an experimental physicist, and pointed out that the speed of light must be immense; he was an observational botanist, who showed that the petals of flowers are never seven or nine. He fought the gathering forces of superstition, and objected that faith

in the omniscience of Allah does not justify ignorance, in effect stating that reference to a final cause is for scientific purposes mere tautology.

Avicenna has well been called the Aristotle of the Moslem world, for his systematization and encyclopaedic summation of all knowledge. *The Canon*, his famous medical encyclopaedia, consists of a million words, and was held authoritative until the middle of the seventeenth century. But he was a good deal more than a medical writer, and is known to have experimented on specific gravity and on the speed of light, which he declared was finite. Also, like Aristotle, Avicenna's attitude was philosophical and terminal. And by his very success he discouraged original scientific advance.

After these large-scale figures there is a sharp decline in Moslem science, marked by a new resurgence of mysticism on the one hand and positivism on the other. Despite the efforts of men like Al-Zarqali and Omar Khayyám, science turned positivistic and toy-minded.

> Instead of being concerned with ideas, they had but a childish interest in automata and in mechanical toys and contrivances. Without further theoretical studies, their progress in that direction was naturally very limited.[9]

Positivism again proved the death of science. After the twelfth century science turned toward the West.

CHRISTIAN-MEDIAEVAL EMPIRICISM

Although the full force of the continuous scientific tradition was not felt in Latin Europe until the infiltration of

[9] George Sarton, *Introduction to the History of Science*, vol. ii, p. 22.

Moslem learning, about the tenth century, there were already signs of a turning toward the scientific temper. Magic was the occasion for pre-Moslem European science, as witness the magic doctor, Marcellus of Bordeaux, who as early as 395 was already beginning to believe in the efficacy of experience. Magic is indeed an old thing in the world, having existed in the midst of the scientific cultures we have discussed, but it had not in these cultures reached the proportions which it attained in Latin Europe. As Lynn Thorndike says, "magicians were the first to 'experiment,' and . . . 'science,' originally speculative, has gradually taken over the experimental method from magic."[10]

The early Christians had not abandoned Greek science; they had been misled by such false theories as those of the bodily humours and the four elements. Thus we find at first popularized compendia of knowledge, such as the *Herbarium* attributed to Apuleius and the *Cosmography* of Aethicus. Between the years 510 and 845 there were the *Consolation of Philosophy* of Boethius, the work of Cassiodorus, the *Etymologies* of Isidore of Seville, the work on plants, animals, and minerals of St. Aldhelm, the *De Natura Rerum* of Bede, the work of St. Agobard, Walafrid Strabo, Macer, and Scotus Erigena. In general, however, it must be admitted that this is a period during which empiricism was at its lowest ebb. Abstract thought was preoccupied with theological matters, and what little interest remained for science took at first the most pedestrian turn, as illustrated by the reliance on early compendia, which degenerated into

[10] *A History of Magic and Experimental Science*, vol. ii, p. 651 f.

mere catalogues of reputed fact. Even in the study of the quadrivium: music, arithmetric, geometry, and astronomy, facts got mixed up with mystical meanings. "Music included a half-mystical doctrine of numbers and the rules of plainsong; geometry consisted of a selection of the propositions of Euclid without the demonstrations; while arithmetic and astronomy were cultivated chiefly because they taught the means of finding Easter."[11]

The continuous scientific tradition was brought to Latin Europe in the conventional manner, namely, by a host of translators and adapters of Arabic and Syrio-Hellenic science. The school of Salerno, which is known to have been a flourishing medical school as early as 946, was one of the first to receive the Arabian heritage. We know of at least two Salernitans, Petrocellus and Archimatthaeus, but even more illustrative of the course of learning is Constantinus Africanus, who was born in Tunis and went to Baghdad to learn Moslem science. From Baghdad he went to Salerno, and later to the monastery of Monte Cassino. Also typical is the case of Gerbart of Aurillac, afterwards Pope, who lived in Christian Spain but had contact with Moslem scientists. He gave an account of Hindu numerals, without the zero, and wrote on music, geometry, and the astrolabe. These men were followed by a host of eleventh- and twelfth-century translators. Among them were Walcher Prior of Malvern, Plato of Tivoli, Robert of Chester, Hermann of Dalmatia, Hugh of Santalla, Gerard of Toledo, and Michael Scot.

[11] W. C. Dampier-Whetham, "Science," *Encyclopaedia Britannica,* fourteenth edition.

It was in the first part of the twelfth century that original science began to appear. William of Conches confirmed the right of free speculation in natural science. Adelard of Bath, the most outstanding scientist of this period, travelled in the Moslem world and studied Moslem science, yet was an original scientist on his own account, far beyond the stage of Moslem science of the time. Besides introducing Hindu numerals, translating Al-Quarizmi's astronomical tables and Euclid's *Elements*, in his *Questiones Naturales* he surveys the field of natural science. Although many of his answers are incorrect, he can be called the first Christian European scientist endowed with the complete scientific mentality. He was impatient of dogmatism and authority and relied on reason backed by experimental verification. Without denying final cause, he stressed the necessity of efficient cause. Since nature "is not confused and without system,"[12] he held that "human science should be given a hearing upon those points *which it has covered.*" Reason without authority and with evidence was his creed; he was "not the sort of man that can be fed on a picture of a beefsteak." He anticipated the conception that science should be value free by saying that nothing in nature is impure.

In the beginning of the thirteenth century there are two major figures, Grosseteste and Nemorarius, and a host of lesser men, e.g. Alexander Neckham, Alfred Sarchel, Witelo, etc. Nemorarius made original contributions to the study of mechanics, especially concerning

[12] All quotations from Adelard cited in Lynn Thorndike, op. cit., vol. ii, pp. 28–30 (italics ours).

trajectories and, more thoroughly, statics. He applied the same mathematical technique to the subject as did later and far more famous physicists. Grosseteste also understood that reason and experience must co-operate in science. He did original work on optics and astronomy, saw the need of reforming the Julian calendar, and stressed the use of magnifying-glasses in observation.

We have next to deal with three contemporaries of the middle thirteenth century: Albertus Magnus, Thomas Aquinas, and Roger Bacon. The first two, known better as theologians, experimented also. Albertus wrote on all subjects of natural science, and appealed to observation and experience, even though his contributions are after all meagre. Aquinas is known to have written treatises on irrigation and mechanical engineering.

The third, Roger Bacon, did not, as is popularly supposed, appear in the midst of an ignorant world hostile to turn of mind. The prior and contemporary scientists which we have mentioned illustrate this point. Indeed, in most ways the times were propitious rather than otherwise. The empirical attitude manifested itself on all sides. Even in art, as Thorndike points out, the sculptors were acute observers of natural objects and indeed went further. They were "breeders in stone, Burbanks of the pencil, Darwins with the chisel."[13] Roger Bacon, then, was in no sense isolated.

But he stood alone in that he emphasized the need for experimentation and mathematics to work together in science, thus pointing science towards mathematics. More especially, he saw the tremendous possibilities of

[13] Op. cit., vol. ii, p. 537.

applied science, and constantly stressed the utility of scientific knowledge. He predicted the possibility of airplanes, steamships, automobiles, the greater practicality of explosives, and the Westward passage to India, which indirectly influenced Columbus through the *Imago Mundi* of Peter d'Ailly. His own experimental contributions were much poorer than his vision of what science should be, and he was more of a herald of science than a scientist, as his inadequate understanding of scientific method proves.

The last half of the thirteenth century showed the halting progress of scientific endeavour. An exception must be made in the case of Peter the Stranger, whose experimental work on magnetism and the compass reveals a good grasp of experimental method. Peter of Spain, who wrote on medicine and psychology, is chiefly interesting because he became Pope John XXI. From the scientist Gerbart (Pope Sylvester II) to John XXI, to say nothing of innumerable monks and friars who were scientists, it is clearly erroneous to believe that the Church was hostile to science during this period. At the close of the century, William of St. Cloud was an admirable observer in the astronomical field, who made the first determination in Europe of the obliquity of the ecliptic.

There is no doubt that there was much empirical science during the period we have just discussed. Experimentation is referred to again and again from the ninth century onward. Nevertheless, little science resulted, and we may well inquire why. The experimental science of Roger Bacon and his kind turns out to be the con-

ception of science as a directly practical affair. An empiricism of this sort finds it hard to distinguish between natural science on the one hand, and astrology, alchemy, and the black arts on the other. But Adelard of Bath sometimes in practice and Roger Bacon often in theory foreshadow true science, where experiment is not the goal of research but a part of the method.

RENAISSANCE EMPIRICISM

There is no break between Christian-mediaeval and Renaissance empiricism. However, it was in the period between 1300 and 1600 that science was started on its correct path. Unfortunately it was in this period that the erroneous positivistic philosophy of science also got its start. The revolt against authoritarian Aristotelianism—pure deduction from principles held without the empirical sanction, the very revolt which was so fruitful—grew until it became bitterly opposed to abstract reason. The rejection of one error seemed to be the signal for the adoption of another. The early humanists made great fun of the logic of Aristotle, which was afterwards lumped with the science of Aristotle as outmoded and ridiculous.

Despite the disrupted condition of Europe in the century of wars and the Black Death, experimental science was carried on as it had been in the thirteenth century; with its random experimentation, uncontrolled theorizing, and emphasis on practicality, and yet with its groping toward true scientific method. There was more interest in magic and the black arts than ever before, and science reached as low a state as it had since

the Greeks. Even the encyclopaedias, to which uninventive periods always resorted, were degraded affairs.

Among such half-baked investigators of science as William Merle, Andalo di Negro, Profatius, Dagomari, Ferminius, John of Picardy, and John of Saxony, attention was paid to arid facts still confused with astrology. Two men stand out from these: John de Murs and Richard Swineshead (called the "Calculator"), who flourished about 1350. The former insisted that facts deduced from instruments can neither be denied nor corrupted, and is said to have made a better astrolabe than the one made for Tycho Brahe. "Calculator" wrote a book in which there is abstract consideration of such physical entities as density, velocity, rarefication, etc. There was furthermore a tendency in the second half of the fourteenth century to discountenance alchemy, astrology, and magic in general. Petrarch, though no scientist, used his great influence to derogate magic. Nicholas Oresme devoted his life to writing books against it, as did his follower, Henry of Hesse. And there were others, such as Groot and Eymeric.

The next seventy years apparently wrought no change in the development of science. Nevertheless, the appearance of such scientists as those of the second half of the fifteenth century, starting with Cusa and ending with da Vinci, shows the widening periphery of scientific interests—extending from flying machines to cartography.[14] Nicholas of Cusa worked on statics, anticipated Galileo by suggesting experiments to demonstrate

[14] *Cf.* Dana B. Durand, "The Earliest Modern Maps of Germany and Central Europe," in *Isis*, vol. xix (1933), p. 486 ff.

the speed of falling bodies, and stressed the importance of measure in physical science. He taught that everything is in motion, the earth along with other planets. Regiomontanus had an astronomical observatory and worked on trigonometry; Toscanelli was an observer of cometary motions, as was Peurbach, who corrected the Alphonsine Tables. John de Fundis explained the process of erosion and the gradualness of geologic change. The emphasis on mathematics of the astronomers is notable, pointing to the use of mathematics in natural science. Pacioli, concerned with algebraic roots, worked with Leonardo da Vinci, who also fully understood that science must be expressed metrically. This he exemplified in optics, astronomy, hydraulics, geology, architecture. Starting always with an interest in particular practical problems, he was led to understand that only by finding the general principles involved could he hope to solve particular problems.

The general interest of the period culminated in one of the greatest of all scientists. Copernicus has direct historical derivation. His teacher, Novara, of the University of Bologna, was thoroughly imbued with the stress laid upon the continuity of nature and the importance of mathematics as taught by the Academy of Florence. Also Copernicus derived encouragement for his heliocentric theory from the classic writers who had favourably mentioned that of Aristarchus of Samos. Nor would his work have been possible without the previous geocentric system of Ptolemy. Copernicus was mainly a mathematical theorist, who observed, but who did not really base his proofs on observation. The theory is non-

empirical, in the positivistic sense of the term, since it did not take into account common sense or the prevailing data of physics. As Burtt points out, the chief merit of his theory over that of Ptolemy's was one of economy, "saving the phenomena" by means of thirty-four epicycles instead of eighty. "Contemporary empiricists [i.e. positivists], had they lived in the sixteenth century, would have been first to scoff out of court the new philosophy of the universe."[15]

Copernicus was a canon and addressed *De Revolutionibus* to Pope Paul III. At this time the Church's attitude toward science was not strictly defined. The Church opposed all heresy in general, in which both magic and science were shortly to be included without any distinction between them. The confusion is illustrated in Pico dela Mirandola, who though a good Churchman believed in science, wrote against astrology, and yet endorsed the Cabala. Later the Church took a much more determined attitude against natural science, based on the seemingly anti-theological import of Copernicus's system.

Meanwhile the descriptive sciences showed signs of development. Vesalius, in Belgium, in his *De Humani Corporis Fabrica*, corrected false anatomical descriptions of Galen and worked on exact anatomy. Eustachius, Fallopius, and Fabricius in Italy continued this work. Fabricius discovered the valves in the veins and was the teacher of Harvey. In Spain Servetus contributed much to anatomy. Palissy explained fossils correctly, and

[15] E. A. Burtt, *The Metaphysical Foundations of Modern Physical Science*, p. 25.

Agricola, in Germany, wrote on stratographic geology. Gesner, the Swiss, studied and classified plants and animals; Bauhin systematized botanical classification. Gilbert of England worked on static electricity and magnetism from a purely empirical standpoint.

But the descriptive sciences showed no such remarkable development as did the physical. Observation unaided is only half of science. It is true that Tycho Brahe, by painstaking observation at Uraniborg and later in Germany, where he made a giant quadrant, furnished the empirical data for Kepler's theoretical formulations. But Brahe alone would never have confirmed the Copernican revolution. Kepler, the mathematician, discovered the laws of planetary motion, showing that the planets describe ellipses about the sun in one focus, and that radius vectors from the sun sweep out equal areas in equal times. Kepler is an arch example of the complete scientist whose main preoccupation is with consistent theory but who insists that it be based on empirical observation. With Kepler's work, as with all great scientific discoveries, the field was opened rather than closed to new inquiry. The laws of planetary motion discovered by Kepler did not check with the old physical ideas, and so led to new physical questions and thus to the development of modern physics in the seventeenth century. All this was foreshadowed and proclaimed by the martyr, Bruno, who predicted such discoveries as the rotation of the sun, the enormous astronomical distances, unknown planets, and the conservation of energy, etc.

In looking back over these three centuries, we note

two kinds of empiricism. On the one side there were those observers and experimenters who were seeking in the facts for almost anything: the positivistic-minded magicians, alchemists, and physicians. Almost as barren was the descriptive science of this period. But on the other side were those experimenting theorists who looked for principles over and beyond the mere appearances and who tested these against empirical fact. Alchemists are 'practical' men; chemists are not. The paradox is presented that science must abstract from practicality in order to arrive at principles susceptible of being practically applied.

However, despite the success of such pure theorists as Copernicus and Kepler, the main opinion persisted even among scientists that science is an affair of demonstration only, opposed to abstract reason. The period under review points the direction that modern science has taken away from the occultists toward a further development of this early science. But the conviction that experimentation is somehow opposed to abstract reason continued to gather momentum and remains to influence science to-day.

CHAPTER III

THE DEVELOPMENT OF EMPIRICISM

If you want to find out anything from the theoretical physicists about the methods they use, I advise you to stick closely to one principle; don't listen to their words, fix your attention on their deeds.

EINSTEIN

SEVENTEENTH-CENTURY EMPIRICISM

THE opposition of science to reason in the beginning of the seventeenth century does not at first show itself in the revulsion against theory but only against the current Aristotelianism, i.e. theory without experiment.[1] As a matter of fact, the scientific theories of that age would seem wild to a modern positivist. If Galileo and Newton had revolted against all theory, science would never have reached its great development. The chief source of the development of science was an acceptance of mathematical reasoning as applied to natural science. Mathematics was encouraged and developed by such men as Napier, the discoverer of logarithms, Descartes, the inventor of co-ordinate geometry, Cavalieri, Fermat, Desargues, Pascal, Wallace, etc., who covered the field from the theory of invisibles to probability and analytic

[1] "In the case of the vase emptied of air, Descartes asserted that either some other material must enter the vase or else its sides would fall into mutual contact; More was prepared stoutly to maintain that the divine extension might fill the vase and hold its sides apart" (Burtt, *Metaphysical Foundations of Modern Physical Science*, p. 138). It occurred to neither to appeal to experiment!

geometry, leading up to the work of Leibnitz and Newton on the calculus. But mathematics seemed to them to have nothing to do with logic.

The rejection of the scholastic system alienated religion and the universities from the new science. The Church burned Bruno in 1600; shortly after this date science began to organize its own academies: the *Accademia dei Lincei* at Rome in 1603, followed by the *Accademia del Cimento* at Florence in 1651, the Royal Society of London in 1662, the *Académie des Sciences* at Paris in 1666, and the Berlin Academy in 1700. Stimulated by the work of the academies the emphasis on observation led to the invention and improvement of scientific instruments: the thermometer, the barometer, the microscope, the telescope, the air pump.

We may note two kinds of science in this century. The mathematico-physical sciences were highly speculative and developed rapidly. The descriptive-biological sciences were equally empirical but less abstractive and speculative, and developed very slowly. The period shows that empiricism is the *sine qua non* of science, but that it must not be held down to the entities of common observation.

In physical science the century opens with Stevinus who set forth the parallelogram of forces, the principle of virtual displacement, and other work on statics. Galileo's chief originality lay in the field of dynamics, though, of course, he had hints from many predecessors.

Galileo was an important experimenter. Through the telescope which he developed he observed sunspots, mountains on the moon, the satellites of Jupiter, the

phases of Venus, etc. His experiments, however, were preceded by a study of the principles involved.[2] The extent to which Galileo was preoccupied with abstract principles and not primarily with mere exemplifications is shown in the manner in which he generalized from the inclined plane to the law of falling bodies, to inertia, and thus to the generalized law of motion, incidentally showing that his youthful discovery of the pendulum principle was a special case of this general law. Galileo understood that scientific method starts with the evidence of common-sense experience but comes to theories, experimentally verifiable, that do violence to common sense.

Boyle is the first modern chemist. Basing his work on that of such men as van Helmont and Jean Rey, in his *The Sceptical Chymist*, 1661, chemistry is treated for the first time as a science, and not as an empirical art for working precious metals and useful medicaments. Boyle, in fact, did for chemistry what Galileo did for physics. Just as Galileo killed Aristotelian mechanics, so Boyle destroyed the authority of the four elements, insisting upon experimentation to find the true ones. Although himself a patient experimenter and an opponent of wild theories, he yet declared the principle that "experience is but an assistant to reason."

Two main influences led to the great synoptic genius of the century, Newton. First, the idea of the universe

[2] By his own account, "the report by a noble Frenchman finally determined me to give myself up *first* to inquire into the *principle* of the telescope, and *then* to consider the *means* by which I might compass the invention" (Dampier-Whetham, *Cambridge Readings in the Literature of Science*, p. 17) (italics ours).

as a perfect mathematical scheme, via Kepler, Galileo, and Barrow, his teacher. Second, the over-emphasis on experimentation characteristic of the whole age, led him to accept Galileo's atomistic mechanism with its objective atoms and the void and its subjetive interpretations. It follows that these should have led to the brilliant scientific scheme, and to the erroneous positivistic conclusions that the laws of nature are mere descriptions of actuality. The scientific scheme was drawn from Kepler's astronomy and Galileo's dynamics, generalized into the laws of motion and gravitation. Thus astronomy and physics became one science. The positivistic conclusions consisted of a philosophy deduced from a method. The method of treating phenomena in isolation had proved successful with Galileo, Boyle, and in his own work. He concluded that explanations of the whole were irrelevant, and declared that he did not touch hypotheses. This negative attitude is positivism, which derived terrific prestige from the fact that it was endorsed by the very man who gave mathematical physics its greatest impetus.

The influence of Newton confirmed the tendency of the century toward a development of the mechanico-mathematical interpretation of the universe, and its investigation by experiment and mathematics. Huygens proceeded to develop the theory of centrifugal force, explaining the flattening of the earth at the poles, and also his wave theory of light. The development of the physical sciences was paralleled by an unfortunate acceptance of positivism.

The biological and descriptive sciences in this century could not avail themselves of mathematics. In spite of

such spectacular achievements as that of Harvey's discovery of the circulation of the blood, and Leeuwenhoek's microscopic discovery of bacteria, more than a century elapsed before biology reached maturity. Their work is almost exclusively on the level of common-sense observation, and mainly notable for the overthrow of the old Greek biological ideas. Sydenham insisted on a material basis for disease, Borelli analysed the mechanics of muscular action, Malpighi worked on embryology and observed the flowing of the blood, and Hooke examined living tissue under the microscope. Similar fresh observations were made in other studies by men freed from old preconceptions, such as Steno, the Dane, who made investigations into the nature of the earth's crust, and Lister, who drew the first geological maps. This valuable spade-work must not be underrated, but it does not represent the same advance as that made by physics. The emphasis on description and classification bolstered the positivistic account of what science is.

Positivism is as old as Hippocrates.[3] It has been easy to show how the century which saw the origins of modern science also saw the acceptance of the old positivistic misunderstanding of science. The rejection of final cause, together with the adoption of a mathematical universe, required a mechanistic atomism. The mistake arose when Galileo assumed that efficient and final cause are not respectively equal to the actual and the mathematical. This equates final cause with actuality, i.e. a completely determined actual world of atoms. Descartes exhibits this error in his 'physicalism': all

[3] *Cf.* Hippocrates, *De Prisca Medicina*, 1–2 (I, 570 ff., L.).

reality is mathematical, but all reality is also extended. Thus all mathematical sciences reduce to the science of physics. This is positivism almost in its modern dress.

However, fortunately positivism was an induction from science in the seventeenth century, and science was not a deduction from positivism. If the latter had been true there would be no science. And in so far as modern science has taken this doctrine seriously, as in the descriptive branches, it has been much hindered. Fortunately and unfortunately, the early physical scientists got hold of a method which they employed without understanding its philosophical meaning.

EIGHTEENTH-CENTURY EMPIRICISM

Accordingly, physical science proliferated tremendously in the eighteenth century. Physics and astronomy had already become largely systematized; in this century it remained for chemistry to accomplish the quantitative systematization.

Astronomy, however, was not without its development, notably in the work of the Herschels, who discovered Uranus, and traced the motion of the solar system to a point in the constellation of Hercules, and who identified over two thousand nebulae; and in the work of Laplace, famous for the nebular hypothesis, and for celestial mechanics. Other branches of physical science which were developed included acoustics and the theory of heat. One of the most prolific developments of physical science in this century was the discovery of the rudiments of electromagnetism. Grey and Wheeler at the beginning of the century found that electricity could

be transmitted through certain substances. Dufay discovered that electrical charges were of two kinds, positive and negative. Von Kleist, Musschenbrock, and William Watson were responsible for the understanding of electrical induction. Franklin showed that lightning was an electrical manifestation. Coulomb demonstrated that an electric charge has magnetic properties. But perhaps the greatest impetus was given to the study by the discoveries of Galvani and Volta at the end of the century, that electricity is generated by chemicals as well as by friction.

Meanwhile mathematics pure and applied continued the splendid development of the previous century, in the work of Maclaurin, who systematized the calculus; Euler, who established analysis as a study independent of geometry. Bernoulli, D'Alembert, and La Grange further applied mathematics to mechanics and dynamics.

By far the most important scientific advance was that made by chemistry. Moreover, it best illustrates the manner in which a science should proceed. The interest in chemistry was given a new impetus when the theory of phlogiston was challenged by the experiment of Dr. Joseph Black in 1756. By heating quicklime he showed that there is a loss of weight exactly equal to the amount of "fixed air" given off, and thus that fixed air (CO_2) is a constituent of the atmosphere. Bergmann soon found that "fixed air" is not air, but the compound, carbon dioxide. Cavendish in 1766 isolated "inflammable air," which on burning condensed into water. The significance of the combination of inflammable air (hydrogen) with the oxygen of the atmosphere to form

water was not understood until Watt and Lavoisier repeated the experiment. Rutherford in 1772 discovered that "inert air" was nitrogen.

Independently Scheele and Priestley discovered oxygen, which the latter termed "dephlogisticated air." He found that it would support combustion and respiration better than ordinary air. It should be noted here that although superficially this chemical experimentation appears as a trial-and-error random affair, it yet was directed by certain *pro tem.* accepted hypotheses, without which there could have been no revelatory experimentation.

How the progress of science works is best shown by the chemical labours of Lavoisier, who put together Boyle's ideas of the elements with the discoveries of the preceding eighteenth-century chemists, to form a quantitative system which gave a terrific spurt to further quantitative research, leading to Dalton's atomic theory and thus to the whole of modern chemistry. Convinced that no ponderable matter disappears in chemical changes, Lavoisier carefully interpreted quantitative results, and in this way arrived at the conclusion that the different "airs" of his predecessors were chemical elements.

Robert Boyle had "pleaded for a closer relation between experimental facts and theoretical speculation."[4] But the unity of experiment and speculation need not be simultaneous in time or contained in the same person. Thus a hundred years elapsed between Boyle's definition of chemical elements and Lavoisier's organization of the table of chemical elements, in which the latter drew on

[4] Douglas McKie, *Antoine Lavoisier*, p. 59.

the *interim* experimental work. Thus without the definition, there would have been no experiments capable of determining specific elements; but without the experiments the definition might have remained an arid hypothesis. With the two, though separated by a century, there resulted a valid and progressive science of chemistry. Had Lavoisier not systematized chemistry, he would have accomplished little more than Priestley, Black, and Scheele, and chemistry would still be an affair of piecemeal and unrelated experimentation.

During the eighteenth century there was much work done in the descriptive and biological sciences. It did not, however, prove to be of the sort which leads to a valid and fruitful system. There was some development in physiology, comparative anatomy, embryology, and 'natural history.' Natural history included botany, zoology, and geology. Physiology was connected with medicine, but was not understood to be significantly related to zoology. Buffon, in his *Natural History*, described all known species of animals. Linnaeus classified all known plants. Both were painstaking and accurate, and the latter's classifications were worked out in great detail. Nevertheless, description and classification do not constitute the abstract systematization which is the aim of science. They do not, because they remain on the qualitative level, allowing of no mathematical application. But as we have seen, science progresses in direct ratio to its employment of the mathematical method. Any elaborate qualitative system, such as Buffon and Linnaeus set up, hinders rather than accelerates scientific progress.

What eighteenth-century science demonstrates is that there are different levels of empiricism. Certainly description and classification are as empirical as the experimentation of Laplace and Lavoisier; but in the former, observation remains at the common-sense level, or at best systematization is accomplished by qualitative categories. These two men worked with quantitative relations, arcana to ordinary observation. For positivism, if logically carried through, description would be the most valid, classification next, and quantitative synthesis last. But progress in scientific research has illustrated that increasing validity lies in the other direction.

NINETEENTH-CENTURY EMPIRICISM

It was in the direction of increasing systematization that the development of the nineteenth century lay, at least in the physical sciences. But it took on a special phase. Many new branches of the physical sciences were explored, and the systematization showed unification by means of interconnection between these new branches. In biological sciences there were brilliant discoveries, far more brilliant than those of previous centuries, but little unification was accomplished.

The increasing specialization and unification are shown in many fields. The relation between chemistry and physics proceeded from Dalton's atomic theory to the periodic law of the table of elements of Mendeléef. The relation between electricity and other forms of energy was first shown by Ampère and Ohm; the relation between electricity and magnetism by Faraday and Maxwell. And all these were embraced by Hertz's discovery

of the electromagnetic nature of radiant energy. In other ways electricity, chemistry, and radiant energy were shown to be interrelated, as with the discovery of electrolysis by Arrhenius, the polarization of light by Fresnel and Young, the X-ray by Roentgen, radioactivity by Becquerel, and the properties of radium by the Curies.

Even more generally, the interconnectivity between forms of energy was exhibited by Avogadro, Sadi Carnot, and Fourrier in their work on thermodynamics, followed by that of Helmholtz, Joule, and Kelvin, Clausius and Boltzmann on the conservation and degradation of energy. To give but one example of the high specialization which took place, we have but to mention so elementary a science as geology, which was divided into the sciences of stratigraphy, mineralogy, petrography, petrology, and palaeontology. On the other hand, many more interconnections between sciences were shown than those we have mentioned, such as physiological chemistry, biochemistry, chemical biology, etc. There were the sciences of spectroscopy, which showed among other things the relation between radiation and chemistry, and crystallography, which showed the relation of geometry to chemistry. In chemistry, geometric properties as well as arithmetic ratios were demonstrated.

Mathematics in the nineteenth century went further than it had in all its previous history. Not only was it developed along with its application to physical sciences, but also, as pure, it forged so far ahead of application that even its adherents could conceive of no possible

field of application for the new systems. Legendre, Jacobi, Cauchy, and Abel developed the theory of elliptical functions, Cayley is responsible for the theory of matrices, and, with Gauss and Sylvester, for the theory of invariance. Gauss, one of the three masters of modern analysis, also set forth the properties of imaginary numbers, while Lobatchewsky and Riemann worked out independent systems of non-euclidean geometry. Weierstrass, Klein, and Poincaré improved the theory of functions. Sir William Hamilton developed quarternions, and Cantor the theory of irrationals and of transfinite numbers.

During the nineteenth century 'natural history' was divided into geology, botany, zoology, and physiology, and these in turn were further subdivided. Two types of investigation in the whole biological field predominated; these we may call the microscopic and the macroscopic. In the microscopic field von Baer in 1828 founded the science of embryology, discovered the human ovum. Ten years later Schleiden and Schwann developed the cellular theory, which Claude Bernard organized into the science of cytology. Virchow, following up this work, recognized the part played by the leucocytes in pathology. Pasteur made his famous discoveries of the functions of micro-organisms in chemistry and the etiology of disease, thus paving the way for a new type of surgical asepsis and medical practice. Following the work of Pasteur, rapid progress was made in segregating the micro-organisms of typhoid, tuberculosis, diphtheria, bubonic plague, etc. And the science of immunology made rapid strides.

The work on evolution accomplished in the nineteenth century started with the speculations of Lamarck, on the origins and development of living organisms. The *Origin of Species*, published in 1859, released a storm of controversy. To be sure, in spite of the enthusiastic claims of Darwin's followers, investigation at this level can hardly be called exact science, though it pointed the way toward scientific research into the laws of heredity, which were worked out statistically by Mendel, and studied at the empirical level by de Vries and Bateson. These latter men created the science of genetics which attempts to discover the mechanism of heredity and variation in biologic elements.

In this century the social sciences may be said to have first been studied with abstraction. They are mentioned here for their ambition rather than for their accomplishment, because it can hardly be said that any social science, with the possible exception of economics, has begun to reach the level of abstraction at which a study becomes a science. Psychology in this period was first officially introduced to the laboratory and began to assume the status of an experimental science.

The nineteenth century also witnessed the culmination of the materialistic conception of the universe, and the triumph of the mechanical model, in keeping with the Newtonian understanding. Accordingly, all actuality was thought to be a strictly deterministic affair, and thus cause-and-effect an historical chain which goes back to the infinite past. In this scheme it was hard to place the mental realm, since it appeared to be an intruder into this tidy universe, and thus insusceptible to the

mathematical laws which otherwise rule. This inability to place mentality was one of the causes of the confusion regarding psychology and the social sciences. But the greatest confusion obtained in regard to the meaning of mathematics: since mathematics had been demonstrated to be the best tool for the discovery of the laws of nature, it must somehow be connected with the material world. On the other hand, since it is a manifestation of the human intellect, it is unmistakably mental. Provided mind and matter are categorically distinct, how can mathematics as imbedded in the nature of things be mental; or how, if it be mental, can it accord with the nature of things? This positivistic dilemma was largely responsible for the misunderstanding as to what science really means. Such was the status of scientific theory at the opening of the twentieth century.

TWENTIETH-CENTURY EMPIRICISM

In this section we must abbreviate, for although the period under consideration is only thirty-six years, so great an acceleration in scientific activity of all kinds has taken place that it would be quite impossible to give more than a cursory account. The exposition must be confined to the most significant developments rather than to the many subsidiary contributions.

The branches of biology which have been developed in the twentieth century are startlingly numerous. There have been marked advances in old biological sciences, and new sciences added to the list. For instance, the science of genetics has gone forward under the leadership of T. H. Morgan, through the discovery of muta-

tions and genes. Bayliss and Starling since 1902 have introduced the science of endocrinology, or the study of hormones, which has had so many repercussions in the practice of medicine. Hopkins, starting in 1912, discovered the vitamins, which have been gradually subdivided into various types. Allergy and immunology have been made into fruitful fields of inquiry.

Two difficulties present themselves to the science of biology conceived as a general science. The first is the random and seemingly unrelated nature of biological investigation, and of discoveries so greatly multiplied that the task of synthesis appears almost insuperable. The second is that in too many fields investigation is still held down by the nineteenth-century conceptions of Darwin and Pasteur. Thus the favourite explanation for the etiology of all disease is still the micro-organic one, and the favourite explanation of all organic modification is still the developmental one of mechanical evolutionism. It is easy to say that the much needed synthesis of biology will come in due time; but time alone is not enough, for the right scientist is required, one who will take a synoptic view which present biology is hardly calculated to encourage.

The case of physical science in the twentieth century has been far otherwise. Indeed, it accomplished the greatest unification of its entire history. Curiously, this unification was first suggested through difficulties encountered with the mechanical model of the universe.

The hypothetical ether was called on to carry different kinds of waves, and thus a substance with properties which could neither be discovered nor imagined. Ex-

periments on the ether led to the famous attempt of Michelson and Morley to determine the ether drift. The null result of this experiment, which was performed in 1887, called for a new explanation, which was first attempted in terms of the old physics. Fitzgerald, Lorenz, and others at the beginning of the century worked out transformation equations which saved the appearances but which called for a systematic deception on the part of nature, incredible to the scientific world. The problem was resolved by the subordination of the Newtonian formulation of space and time. Einstein in 1905 announced his special theory of relativity, whereby space and time are relative to a given frame, the speed of light remaining the only constant. Minkowski, in 1908, employing non-euclidean geometry, showed that what the special theory involved was a four-dimensional continuum. Einstein in 1916 with his general theory of relativity worked out the mathematical formulation in terms of the tensor calculus of Levi-Civita, a postulational system giving the formulations for any frame. It has no picturability.

Sub-atomic physics underwent a similar revolution, starting from the discovery by Becquerel in 1896 of radio-activity, whereby the atom was shown to be a complex of still more fundamental particles. Five years later Max Planck discovered that the interchange of energy proceeds not gradually, as had been supposed, but rather discontinuously, in atomic lumps of action called quanta. Meanwhile attempts at a mechanical model were made successively by Thomson, Rutherford, and Bohr, comparing sub-atomic mechanics with celestial

mechanics. It was discovered, however, that the interchange of energy within the atom in no way responded to mechanical treatment, but that Planck's principle of the quantum was involved. With Heisenberg, Dirac, and Schrödinger employing the theory of matrices, non-commutative algebra, and Hamiltonian functions, in the period 1925–26, a new sub-atomic theory, sometimes called the quantum theory, was devised entirely in non-picturable terms—one which contradicts practically every tenet of classical mechanical physics.

Thus in both departments of physics, the mechanical model definitely broke down and was supplanted by the mathematical model. "Material points consist of, or are nothing but, wave systems."[5] The change from the mechanical model to the mathematical model involves the change from categories of sense experience to categories of objective instruments. As Planck himself has said, "It is much easier to establish exact physical laws if the senses are ignored and attention is concentrated on the events outside the senses. . . . The eye gave way to the photographic film, the ear to the vibrating membrane, and the skin to the thermometer."[6] Physics has left the description of actuality for the systematic exploration of relations which are its invariables.

The most striking thing about abstract science is its use of mathematics, and particularly significant is the relatively high applicability of scientific principles which were formerly considered pure, as in the use of matrices,

[5] Schrödinger, cited in Dampier, *A History of Science*, p. 412.

[6] Planck, *The Philosophy of Physics*, pp. 16–17 (George Allen & Unwin Ltd.).

the tensor calculus, etc. The development implies a higher and higher level of abstraction, which, as it rises in abstractiveness, accelerates in its advance.

But in the abandonment of the conception of science as a description of actuality, certain difficulties ensued. Causality no longer appeared valid, and indeterminacy in actual sub-atomic events refuted the locked temporal chain of cause and effect. The implied moral, that science deals with a mathematical realm, of which actuality is only a probabilistic approximation, has been erroneously read as though causality were ruled out of the physical world, and as though all that could be known were laws of probability. The disappearance of the mechanical model and of the old interpretation of causality has been responsible for two kinds of interpretation of what science really means. On the one hand, there is the school of objective mentalism of Eddington and Jeans. On the other hand, there is an attempt by the conservatives to save what can be saved of the old picturable model,[7] at the expense of the reality of natural law. This has taken the form of the revival and emendation of positivism.

EMPIRICISM MISUNDERSTOOD

This rapid survey of the history of science has brought out the fact that empirical science of a sort has had a continuous history from early Greece to modern times. The halting progress of science prior to the middle of the sixteenth century apparently cannot be blamed on a

[7] *Cf.* Bridgman's attempt to find the residue of the "physical models of classical theory" in the text accompanying the equations of mathematical models, in *The Nature of Physical Theory.*

lack of experimentation but rather on the use to which experiment was put and to the narrow practicality of scientific ideals. Experimental science had to rise out of magic and into the use of mathematics; whereas theoretical considerations had to come down out of theology and submit themselves to empirical checking. The meeting of both movements resulted in modern science.

Experimentation seems to have gone hand in hand with unsuccessful as well as with successful scientific endeavour. Certainly there has been no valid science without it, as is exemplified by Archimedes and the Alexandrians as well as by Galileo and Faraday. But just as certainly there has been much invalid science with it, as is exemplified by the alchemists and astrologers of the fourteenth century. We may conclude that experimentation does not make the difference between science and pseudo-science, although it is one of the necessary elements of true science. What then is the difference between the kind of experimentation which produces science and the kind which fails? A consideration of the history of science should suggest an answer. Where empiricism is understood as held down strictly to common sensory observations, science can get no further than description and classification, or so-called empirical laws, i.e. inductions drawn at the qualitative level of common sense. When, however, empiricism is understood as the discovery of relations which sensory observation leads to but which are not themselves sensory, there emerge the beginnings of a quantitative science with its abstract causal laws.

Had Galileo drawn only the induction that all falling bodies drop at the same rate irrespective of weight, this would have been a positivistic summary, a 'statistical law,' which incidentally would only have been true more or less, since it would not have taken into consideration countervailing forces present in uncontrolled conditions. So framed, it would certainly never have suggested the law of inertia. It is because such scientists as Galileo and Newton recognized the empirical nature of entities like 'force,' 'space,' and 'mass,' which are not completely equatable with anything actual, that they were able to formulate laws of a generality great enough to be applicable to varying conditions of actuality, and thus practical in the largest sense of the word. The reason the positivistic Greek physiologists did not discover the circulation of the blood, may be laid to their prohibition against looking for anything which was not immediately perceptible, the circulation of the blood being not in itself a sensory fact but observable only in its function. No such non-sensory empirical fact can be arrived at without sought-for relations. This involves theory as well as fact.

The guiding ideas and the procedure of the great scientists illustrate that they have always been preoccupied with the discovery of relations and with the necessity of weaving these into an abstract system. They went to the sensory phenomena of nature only for suggestion, allowance, or confirmation of theories of underlying relations which could be formulated as abstract causal laws. Convinced of the continuity of nature, they have always been concerned to show the interrela-

tions of these causal laws, thereby endeavouring to reveal nature's system. This they have sought to accomplish in two ways. First, they have aspired to consistency, order, and unity within their sciences, by finding laws of a generality which would show all laws of a lesser generality as special cases. Secondly, they have worked toward more specific relations. This direction of endeavour has been misunderstood to mean the direction toward actual sensory fact, but it is nothing of the sort. 'Tuberculosis' is a more specific function than 'respiratory disease' or 'disease,' but none of them refers necessarily to actual facts.

This attempt to find the abstract regularity in phenomena cannot, however, be arrived at by pure speculation, as Plato supposed. But neither can it be found by dumb observation, as Francis Bacon supposed. It can be found only through the judicious use of speculation carefully held down by, and corrected according to, the observation of phenomena. Once tested, principles become in turn empirical facts, and are employable as data for further speculation and empirical demonstration.

Philosophical empiricism is therefore clearly not the implicit philosophy of science, since it holds that the only valid appeal to truth is limited to sense experience, and that by consequence abstract reasoning is suspect. This was the view of the British school of Locke and Hume. Supposing that science was talking about phenomena and not about abstract functions, Hume showed that sensation presents no linkage of cause-and-effect relation, but only the temporal succession of one event after another. It would follow from this that causality

is a mental grouping of sense experiences, and thus insusceptible of objective proof. This contention was based on an entire misunderstanding of what science really says. Science does not say with Hume that the cause of the melting of wax is the heat which precedes the melting. Rather it states the general principle that heat accelerates the molecular velocity, and that at a certain velocity the mass reaches the liquid state. It is not the temporal succession of the demonstration which is interesting to science, but the conditions necessary for this transformation—at any time or place. This function *is* the linkage of cause and effect, which Hume stated to be non-empirical. Such a function is not at the level of common-sense experience, but it is empirical none the less.

Although the empirical philosophy did not stop scientific progress, the effect of it was toward reinforcing scientists in their erroneous belief that experiment is the whole of method and that principles are summaries of actual experiments. Plainly, this does not agree with the procedure of science. With the employment of abstract reason and the use of general principles, not to mention mathematical analysis, scientific empiricism will be recognized as essentially a rational and logical procedure. Thus the distrust of abstract reason by the scientists is misplaced; it should be directed against unbridled rationalism. Yet it is because of this anti-rational orientation that modern science has come to look askance at philosophy, and has preferred to take refuge in the irrational doctrines of positivism. What science objects to is *bad* philosophy; but it does not avoid bad

philosophy by running from one bad philosophy to another equally bad. The time has come when science faces the neccssity of discovering its true philosophy. This can be accomplished only by a thorough-going analysis of empiricism.

CHAPTER IV

MODERN MISCONCEPTIONS OF EMPIRICISM

Both romantic idealists and positivists banish rigorous reason as a true integral part of the natural world.

M. R. COHEN

FROM HUME TO COMTE

WE have shown that the philosophical understanding of empiricism does not accord with the procedure of science. Although such radical empiricism as Hume and his followers set forth did not affect this procedure, it did reinforce the scientists, already biased in its favour, in their view that science is primarily empirical and that empiricism is basically irrational. Philosophical thought from Hume onward did not change this tendency but rather emphasized it. In spite of the many reactions against radical empiricism (positivism) in philosophical circles, reactions which were regarded by the scientists as flights of unscientific fancy and moony-eyed idealism, the positivistic view became more and more widespread.

The eighteenth-century Enlightenment took for granted the world-view of mechanistic materialism as a locked system, but dwelt on the freedom of the human mind to manufacture whatever conceptions it required and thus to make over social life. Here was an absolute hiatus between the brute facts of experience and the reasoning powers of man. Diderot, Condillac, Condorcet, and other 'rationalists' interpreted this dichotomy as

favourable to the intellect; thus the title of the 'Age of Reason' has been given to this period.

But to Rousseau and the romantic school, another interpretation appeared just as satisfactory, namely, that reason is a spurious and unreliable guide, and that man should rely altogether on feeling and 'natural fact.' Disregarding the point that Rousseau was hardly a thinker at all, and that Hume was a very exact thinker, we may note that both arrived at the same conclusions due to the premises they implicitly accepted: that sense experience and *not* abstract reason gives the most indubitable evidence on which to build permanent and positive knowledge.

Without considering the tremendous import of Kant's attempted resolution of the dilemma between reason and phenomena, it may be said that in its effect the philosophy of Kant was more influential on the side of radical empiricism than on that of rationalism. Kant maintained that we cannot have knowledge of the supersensory, and that metaphysics which attempts it is pseudo-science. Kant himself modified his position on the impossibility of metaphysics, yet the notion that metaphysics is 'mind-spinning' prevailed in scientific-philosophical circles. Thus, more and more, scientists and the educated public in general were led to the belief that science is altogether concerned with the sensible world of phenomena, and that philosophy is engaged in talking about mere concepts of the mind. That such a belief should assume the proportions of an explicit system was to be expected. This was accomplished by the positivistic school of Saint-Simon, Comte, Littré, in France,

and the utilitarian school of Bentham and the Mills in England.

EARLY FORMULATIONS OF POSITIVISM

The primary purpose of Comte's positivism was the rational reform of society by scientific method, thus instituting the idea of sociology, or the science of society. In so doing, of course, he had first to define science and scientific method. Science according to Comte is that stage of positive knowledge which is reached after traversing the theological and metaphysical stages. The third stage, the positive or scientific, abandons the attempt to find absolute causes and contents itself with invariant relations between facts established by the method of observation. This knowledge is sufficient for practical purposes, and the attempt to reduce everything to unity is a mere subjective tendency of the mind. Experience proves it impossible. Comte was not a scientist and had no knowledge of scientific experimentation. So he concluded that invariant relations could be found by the mere observation of phenomena at the ordinary level of sense experience. If he had known more about science he might have realized that the objects of observation of experimental science do not stop with empirical entities overt to untutored eyes. But through lack of this understanding, he was led to the false assumption that the laws of science are mere summaries of past observation.

John Stuart Mill arrived independently at a position very close to that of Comte; but, as he himself asserted, he was for a time a disciple of Comte, though he de-

veloped another side of positivism. He went much further than Comte into the methodology of science, particularly into the inductive method. It was the emphasis on the inductive side of scientific reasoning which led Mill to under-emphasize the part of deduction and to see induction too narrowly as derived from sense experience. Thus an induction was for him a generalization of uniformities in phenomena, and this uniformity among phenomena he called the laws of nature. A law to Mill was a name for observable uniformities and not in itself a part of nature. Looked at in the historical order, cause and effect became the inevitable temporal relation of antecedent to consequent. Thus he did not understand causality non-temporally, as it is presented in such a science as chemistry, i.e. as the involvement of one function with another, capable of being presented as the succession of actual experiments which exemplify it. Mill's failure to isolate causality from the temporal order was occasioned by his acceptance of the associationist psychology of Hartley which defines ideas as the mere succession of images in the mind. Thus scientific functions were not disconnected from the perception of them, and logical factors were confused with their conception by the mind, i.e. logic was made a branch of psychology.

The net effect of Mill on those scientists who read him at all was toward increasing their conviction that the whole of science is the observation of phenomena, and that the concepts of science are mere mental summaries of experience. So-called latter-day English empiricism turns out to be positivism. From it flow modern posi-

tivism on the one hand and mentalism on the other. Neither Comte nor Mill understood the whole of scientific procedure. Many of the principles of science derive their authority from the manner in which they embrace and generalize other principles already found, and often it is not until later that they are experimentally 'proved.' Comte and Mill fell back into almost complete subjectivism in the very act of seeking a firm empirical objective basis for science. Psychological certitude has nothing to do with objective truth (as far as science is concerned).

> The certainty which science aims to bring about is not a psychologic feeling about a given proposition but a logical ground on which its claim to be truth can be founded.[1]

The unfortunate introduction of the observing subject into the observed field has led the understanding of empiricism astray.

MACH, POINCARÉ, PEARSON

The positivistic bent of scientific theory was carried forward into the later nineteenth century principally by three men: Mach, Poincaré, and Karl Pearson. It is interesting to note that these three men were scientists, and that their work had a wide currency among other scientists, thus showing the greater and greater acceptance of positivism by scientists themselves.

Ernst Mach, a physicist, attempted to interpret physics entirely in terms of psychology. That is to say, he held that science ought to be "confined to the compendious

[1] Cohen, *Reason and Nature*, p. 84.

representation of the actual."[2] Mach meant that sensations make up the stuff of reality, whether experienced or not, but ideas which connect them are mental fictions. Two things are evident in this scheme: first, that science is pure description of sensations, and secondly, that no natural laws exist, laws being but summatory fictions. On this view, scientific entities, such as atoms, are fictions, but sensations (which never appear atomistically!) are real atoms. In this extreme attempt to hold science down to the vividity of actuality and disallow real mathematical relations, we get no picture of anything which resembles the world of science, for science is concerned not with sensuous imagery but with abstract relations. Mach escaped complete subjectivism only by using the term 'sensation' as though it were non-psychological. We can already see how close to positivism is subjectivism, though the ambition of the former is to escape 'mind-spinning' and to concentrate on the objective and undeniable.

In the case of Poincaré the same tendency is evident. Poincaré was a positivist, yet scattered throughout his writings there was the attempt to get outside of the charmed subjective circle. Instead of trying to make psychological sensations the stuff of the world, as did Mach, he took the social mind, particularly as it understands mathematical relations, and made it the objective world.

Does the harmony the human intelligence thinks it discovers in nature exist outside this intelligence? No, beyond

[2] Mach, *The Analysis of Sensations*, preface to the fourth edition (Eng. trans. Chicago, 1914, Open Court), p. xii.

doubt a reality completely independent of the mind which conceives it, sees it or feels it, is an impossibility. A world as exterior as that, even if it existed, would for us be forever inaccessible. But what we call objective reality is, in the last analysis, what is common to many thinking beings, and could be common to all; this common part, we shall see, can only be the harmony expressed by mathematical laws.[3]

But despite this effort to set up a quasi-objective realm of pure mathematics for science, Poincaré is thrown back upon subjective feeling in defining objective fact.

When it is said that we 'localize' such and such an object at such and such a point of space, what does it mean?

It simply means that we represent to ourselves the movements it would be necessary to make to reach that object.[4]

Of course this is nothing more than pure operationalism of the later Bridgman variety. And that it reduces to subjectivism of the Machian brand Poincaré himself could not avoid.

None of our sensations, isolated, could have conducted us to the idea of space; we are led to it only by studying the laws, according to which these sensations succeed each other.[5]

What Poincaré is constantly confusing is the way in which ideas are conveyed to the mind and the meaning of those ideas. In discussing mathematics this leads him to confuse mathematical relations with the symbols used to express them. Certainly it may be admitted that mathematical symbols are a convention, without thereby

[3] Poincaré, *The Foundations of Science*, p. 209.

[4] Ibid., p. 70.

[5] Ibid., p. 71.

admitting that the relations they express are also conventional, arbitrary, or mental.

Karl Pearson agrees with Mach and Poincaré in seeing scientific laws mainly as summaries of experience, psychological or historical. Scientific laws

> simply *describe*, they never *explain* the routine of our perceptions. The sense impressions we project into an 'outside' world.[6] It [scientific law] is a brief description in mental shorthand of as wide a range as possible of the sequences of our sense-impressions.[7]

This is the familiar error of assuming that because all which the eye sees is seen by the eye, all must be of the nature of *eye*. Thus Pearson too confuses scientific laws with the sense-impressions whereby scientists have been able to discover them. The confusion is between the psychological fact of knowing and the logical conditions of knowledge. Quite naturally Pearson as a positivist denies any connection between sequences of events other than the mental "routine of perceptions," and thus with Hume makes causality a non-empirical fact.

> We are neither able to explain why sense-impressions have a definite sequence, nor to assert that there is really an element of necessity in the phenomenon.[8]

All positivists make the mistake of confusing causality with the temporal sequence of experience, the latter being only a special and therefore often misleading exemplification of the former.

[6] Karl Pearson, *The Grammar of Science* (London, 1892, Scott), p. 99.
[7] Ibid., p. 135.
[8] Ibid., p. 140.

"The compendious representation of the actual" of Mach, the "sensations [which] succeed each other" of Poincaré, and the "routine of our perceptions" of Pearson, are all the same. A like confusion prevails in all three: that of identifying the succession of experience with that which is experienced, the first being a psychological, the second a logical, fact. If with these men we wish to confine science to descriptions of actual happenings, we get away from the succession of psychological experiences only to fall into the temporal succession of history. There is an objectivity to the latter which has recommended it to scientists.

THE MENTALIST VIEW

The "compendious representation of the actual" might have passed muster as a description of science in Mach's day, when the mechanical model of the universe dominated physical science. But with the introduction of relativity and quantum physics, the mechanical model broke down. Whatever the explanation, it was recognized that the representation of physico-mathematical equations could no longer be anything picturable. Thus no description of actuality answers to the new physics. This fact left scientists in a quandary as to how to explain what scientific 'concepts' meant. A whole new flood of scientific-philosophical explanations was poured forth. In general these were divided into two classes: the mentalistic interpretations and the operational interpretations.

The mentalist view has been made popular through the work of Eddington and Jeans. According to them,

science is concerned with the mental constructions on an objective reality which is entirely unpicturable and, in fact, unknowable *in esse*, but which is represented best by mathematical symbols. Their eventual conclusion as to the substratum of physical reality is that it is "mind stuff." This, as Eddington says,[9] is not exactly mind and not exactly stuff, since it is not identifiable with individual consciousness nor spread out in space and time.

Jeans, taking mathematics as the nearest human formulation of reality, decides that the stuff of the world is mathematical thought, but again not thought in any individual's mind, but rather in the mind of God. Clearly both men believe that science is concerned with finding not the *what* of reality but the *how*, and that this can be represented mathematically in terms of symbols, which to Eddington are "pointer readings" and to Jeans pure mathematical symbols. The merit of these theories is that they point to the extreme abstractive character of the scientific subject-matter. They have incidentally shown that the scientific 'picture' cannot ever be comprehended in terms of common-sense actuality.

Despite this merit, however, the total effect of denying the objectivity of the scientific subject-matter has brought the investigator back into the objective scientific field. 'Mind-stuff,' as set forth by Eddington and Jeans, turns out in the end not to be dependent on the mind. If it serves any purpose to call this 'mind-stuff,' when it is neither mind nor stuff, well and good, but interpreted in the light of other passages in Eddington's books, it must be insisted that he does seem to mean both mind

[9] *The Nature of the Physical World*, p. 276.

and stuff. Thus the mental is confused with the physical, with the added assumption that the mind never really knows the physical. From this hash of subjective and objective idealism, it is small wonder that scientists should rebel, confirmed in their old opinion that philosophy is time wasted over words, and that the life of science consists in doing things. The mentalist interpretation plays havoc with empiricism, since according to it observed phenomena are only the mental interpretations of an unknowable reality underlying the phenomena. This seems to leave no basis for agreement other than private opinion; and from the scientific point of view is its greatest source of repugnance.

The most cogent argument against the mentalist view is to show that it resolves nothing. The determination to call all things stuff of the mind is to put them all on a parity. But science is known for the distinctions it makes and not for the names which it can apply equally to all phenomena. Mind-stuff, like any term which can be equally applied to all things, leaves the theory of science exactly where it was.

THE LOGICAL POSITIVIST VIEW

From out this maze of metaphysical theory, the scientists have sought to save themselves by the discovery and embrasure of that philosophy of science which seems to contain the least metaphysics and to permit scientists to confine their speculations and efforts to the empirical. Often called operationalism by scientists, this theory is known more generally as logical positivism.

The position has been put forward and systematically

formulated by the logical positivists of the Vienna Circle: Wittgenstein, Schlick, Reichenbach, Waismann, Neurath, and Carnap. These men are by profession philosophers whose chief interest is science, but they are all violently anti-metaphysical. They trace their trend of thought back to Comte and Mach, but assume a much more radical position. Logical positivism asserts that all metaphysical questions are meaningless, e.g. the question of whether the nature of the physical world is mind-stuff or matter or subjective interpretation. All problems which cannot be verified in experience come under this category.

> Most propositions and questions, that have been written about philosophical matters, are not false, but senseless. We cannot, therefore, answer questionsof this kind at all but only state their senselessness.[10]

And Carnap presents exactly the same point of view.[11] His explanation is as follows:

> But this question [the reality of the physical world] has no sense, because the reality of anything is nothing else than a possibility of its being placed in a certain system . . . and such a question only if it concerns elements or parts, not if it concerns the system itself.[12]

Every science must express itself in the language of physics, the "protocol language."

> In our discussions in the *Vienna Circle* we have arrived at

[10] Wittgenstein, *Tractatus Logico-Philosophicus*, 4.003.

[11] Carnap, *The Unity of Science* (London, 1934, Kegan Paul), p. 21.

[12] Carnap, *Philosophy and Logical Syntax* (London, 1935, Kegan Paul), p. 20.

the opinion that this physical language is the basic language of all science, that it is a universal language comprehending the contents of all other scientific languages. . . . Dr. *Neurath*, who has greatly stimulated the considerations which led to this thesis, has proposed to call it the thesis of *physicalism*.[13]

For example, psychology would reduce to behaviouristic psychology; biology to descriptions and terms which reduce to something perceptible and not to non-empirical entities; and so on.

This school accepts logic without question and uses it to reinforce its positivism. The logical positivists say that logical analysis is the only real problem of philosophy.

The function of logical analysis is to analyse all knowledge, all assertions of science and of everyday life, in order to make clear the sense of each assertion and the connections between them. One of the principal tasks of the logical analysis of a given proposition is to find out the *method of verification* for that proposition.[14]

For example, this school would say that the logical analysis of the concept, metabolism, shows that it does not refer to a mysterious non-empirical entity but to an observable process which must be specified in terms of physical measurement. Thus to discuss what metabolism is in itself is meaningless. The Vienna Circle's reliance on logic and the doctrine of physicalism or the "protocol language" which is applicable to all science, inevitably led to the doctrine of the unity of science.

[13] Carnap, *Philosophy and Logical Syntax*, p. 89.
[14] Ibid., pp. 9–10 (italics ours).

Because the physical language is thus the basic language of Science *the whole of Science becomes Physics.*[15]

If we have a single language for the whole of science the cleavage between different departments disappears. Hence the thesis of Physicalism leads to the thesis of the *unity of Science.*[16]

There is a tendency on the part of some members of the Vienna Circle to emphasize the logical side of logical positivism. It is possible to endorse at least some of the utterances of Moritz Schlick, which, in so far as they are valid, seem to us to depart from the position of positivism. Schlick says, for instance, that

the question of meaning has nothing to do with the psychological question as to the mental processes of which an act of thought may consist.[17]

This denial of the primacy of sense-experience is not in keeping with the radical empiricistic view of most of the logical positivists. But Schlick ventures even farther than this in his defence of logic.

It must be emphasized that when we speak of verifiability we mean *logical* possibility of verification, and nothing but this.[18]

The truth simply is that such an assertion contradicts the postulates of the modern logical positivistic school, and is much more conformable with the realistic view, which will be examined on page 96.

Logical positivism may be summarized under two headings, the logical and the empirical.

[15] Carnap, *The Unity of Science*, p. 97. [16] Ibid., p. 96.

[17] *The Philosophical Review*, vol. xlv (1936), p. 355.

[18] Ibid., p. 349.

The logical position states the valuable truism that logical analysis involves the relations of parts of a system to the whole system, and has nothing to say about the system as a whole or about anything beyond that system. The analysis of the building bricks, which may happen to be part of a house, into their chemical constituents has nothing to say about brick or about house. And to bring such questions into the logical analysis is irrelevant, or, in terms of the positivist in this connection, "meaningless." But the statement that such questions are irrelevant at this level of analysis certainly does not imply that they are altogether irrelevant to the whole of knowledge, or that they are meaningless. Meaninglessness in one connection does not imply meaninglessness in another. Neither is the question of the reality or unreality of the physical world meaningless, even though it is irrelevant to physics *qua* physics. The positivists have done a service and a disservice: a service by calling attention to what should be a platitude, and a disservice by holding down speculation to analysis.

The empirical position of logical positivism asserts that whatever cannot be verified in experience is meaningless. Stated in this manner, the proposition is a truism but one which has given rise to a vicious notion, namely, that what *has not* been done *cannot* be done. Unfortunately, the positivists mean by 'cannot,' 'has not.' And this entitles them to throw out as meaningless all speculations which concern unsettled problems. The erection of a failure into a principle serves only to insure the continuance of the failure. The history of science is full of examples of the verification of that which was at one

time thought to be permanently unverifiable.[19] In ancient times the distances of the stars from the earth was deemed unverifiable. But if on the positivist principle the problem had been thrown out as meaningless, no verification would ever have been made. Indeed the whole advance of science has been that of verifying what was once pure speculation. The problem of the nature of beauty, for instance, would be considered by the logical positivists a meaningless question. Perhaps it is. But certainly no one has ever been able to demonstrate conclusively its meaninglessness. If we should proceed on this assumption, the problem would come to an end and be dropped from speculation. If, however, we should proceed on the opposite assumption that it might have

[19] To make the positivistic assertion that this or that cannot be done is contradictory to positivism, since it represents reasoning which has gone far beyond the empirical facts. Quite an imposing list could be drawn of accomplishments which had been formerly proved to be 'impossible of accomplishment.' For instance, Aristotle said that "one may be satisfied that there are no senses apart from the five"—(*On the Soul*, book iii, 1)—yet modern physiological psychology has discovered others. "Legendre said of a certain proposition in the theory of numbers that, while it appeared to be true, it was most likely beyond the powers of the human mind to prove it; yet the next writer on the subject gave six independent demonstrations of the theorem. Auguste Comte said that it was clearly impossible for men ever to learn anything of the chemical constitution of the fixed stars, but before his book had reached its readers the discovery which he announced as impossible had been made" (C. S. Peirce, *Collected Papers*, 6.556). "We [wrote J. Müller] shall probably never attain the power of measuring the velocity of nervous action, for we have not the opportunity of comparing its propagation through immense space, as we have in the case of light" (J. C. Flügel, *A Hundred Years of Psychology*, p. 89). But a few years later, as Flügel points out, the task was accomplished by Helmholtz, who had been one of Müller's pupils.

meaning, some verifiable knowledge might be discovered which the positivist would then accept as meaningful. We can therefore allow the statement that whatever cannot be verified is meaningless, but it will not make any difference to the procedure of science except as a caution against unbridled speculation.

Logical positivism helps to clear up certain logical misunderstandings about science, but it does not constitute a programme for scientific activity. And its physicalistic understanding of empiricism is an insufficient formulation. For science to accept entire the philosophy of the Vienna Circle would be equivalent to signing its own death-warrant. Empiricism is something broader than the caution to hold science down to the sensory.

THE OPERATIONALIST VIEW

The second group of modern positivists whose views on empiricism we have to consider is not composed of professional philosophers but of physical scientists, who have in a sense stepped out of their role as physicists to consider the theoretical nature of the scientific subject-matter. Prominent among them are Lenzen[20] and Bridgman,[21] Heisenberg and Dirac. In general, the position of Heisenberg and Dirac is expressed by that of Lenzen.

> In agreement with the empiricistic point of view my theory of science assumes a subjectivistic criterion of reality. A physical body is a class of aspects which are or can be given to some mind. In general one may say that the criterion

[20] *The Nature of Physical Theory.*
[21] *The Logic of Modern Physics.*

of the reality of aspects is that they be possibilities of experience. . . . The objectivity of the physical order is grounded in correlations between aspects given to different minds.[22]

The derivation from Mach, which Lenzen freely admits, is obvious in the above passage. "Aspects" are the same as Mach's "sensations," and they both turn out to include more than sensations, namely, "*possibilities* of experience." This is the same question-begging device employed by Mach.[23]

But let us read a little further.

All entities of physical science can be characterized in terms of experienceable aspects.[24]

How we are to distinguish between what is "experienceable" in advance of experience and what is not, is not suggested. Thus Lenzen concludes by accepting positivism and seeing that it implies all that subjectivism implies.

. . . the positivistic criticism is that a subjectivistic criterion should be employed.[25]

Let us see which way his theory, that all the entities of physical science can be characterized in terms of "experienceable aspects," leads. It led with Mach and Ostwald to the rejection of molecules and atoms as fictions because these had not yet been experimentally observed. It leads with Lenzen to the acceptance of microscopic entities not as fictions but as realities, because their existence is now inferable from observation. Thus the same premises accepted by Mach and Lenzen lead

[22] Lenzen, op. cit., p. 6.

[23] See above, p. 80.

[24] Lenzen, op. cit., p. 8.

[25] Ibid., p. 10.

them to contradictory conclusions. This confusion well illustrates that much can exist which is not at any given time experienced, and it also exhibits the question-begging device of "experience*able*" which offered no help to Mach. As a matter of fact, none of the entities of physical science are aspects of experience *per se*, though all are inferred from experience.

That Heisenberg and Dirac agree with positivism, Lenzen has noted. For instance, he quotes Dirac,

> A fraction of a photon is never observed, so that we may safely assume that it cannot exist.[26]

Whether a fraction of a photon can exist or not we do not know, but certainly we can say that the fact that it has never been observed is no proof of its non-existence any more than the fact that the planet Pluto had not been observed in 1900 proved its non-existence. Did the heavy isotope of hydrogen come into being in 1935? This kind of nonsense is just the sort of thing which kills off speculation as fast as it is attempted, since science has always gone on the assumption that there must be entities and processes to be discovered which nobody has yet experienced.

Let us now turn to the work of P. W. Bridgman, another scientist whose theory of science has had much influence in America. Bridgman admits that his work is derived largely from Clifford, Stallo, Mach, and Poincaré, and he brings their theory to bear on the new concepts of physics. Particularly noticeable is the derivation from Poincaré.[27] He has taken the quasi-objective

[26] Lenzen, op. cit., p. 10.

[27] See above, p. 81.

side of positivism which makes physical concepts not the summaries of sensations but the performances of experiments. This is "operationalism."

> In general, we mean by any concept nothing more than a set of operations: *the concept is synonymous with the corresponding set of operations.*[28]

Bridgman does not admit any validity to concepts other than as summaries of operations. This insistence on operations seems to satisfy the demand of science to be empirical, and seems, moreover, to hold science down to the laboratory and to do away with all metaphysical speculation. But it really cuts the ground from under empiricism and is incurably subjective, since it ends by telling science that its concepts do not refer to entities but to the perception of scientists.

That the subjectivity of the observer must on this view enter into the operations observed, to an indeterminable degree, is admitted by Bridgman when he says that

> it is evident that the nature of our thinking mechanism essentially colours any picture that we can form of nature. . . .[29]

Thus Bridgman not only denies the objectivity of the entities of science but he confounds the issue by insisting upon a subjective criterion while admitting the existence of a dualism whereby the mind contributes part and the operations contribute part. This leads to an utter distrust of rationality, even to the denial of the validity of logic. Bridgman tells us that

[28] Bridgman, *The Logic of Modern Physics*, p. 5.
[29] Ibid., p. xi.

our conviction that nature is understandable and subject to law arose from the narrowness of our horizons, and . . . if we sufficiently extend our range we shall find that nature is intrinsically and in its elements neither understandable nor subject to law. . . .[30]

If nature is not subject to law, then the whole of science is a fruitless proceeding. What, then, are the discoveries of science, and why do contemporary scientists whose horizons have recently been broadened continue to look for uniformities in nature? The mere fact that physics has so far discovered no way to study the occurrences within the atom except in statistical computations of results is used as an argument to show that causality does not apply to the sub-microscopic world, and indeed that it does not apply at all, i.e. causality is not in any way a principle of nature. Surely to erect a failure into so general a principle with which to contradict all prior assumptions of science is a ridiculous attempt.

The same criticism which applies to all positivists applies to Bridgman. There is exhibited the failure to distinguish between the fact of perception and that which is perceived; between the operations or experiments which reveal laws and the laws thus revealed; between the observed and the existence which is covered by the term 'observable.' In attempting to make empiricism the

[30] "The New Vision of Science" in *Harper's* for March 1929. In a later work this is contradicted by Bridgman: "Chance has no meaning except in a setting of order," *The Nature of Physical Theory*, p. 123. In the latter work, in which Bridgman brings his position up to date, there is so much confusion and contradiction that further refutation is unnecessary.

whole of scientific method, the very idea of empiricism is rendered incomprehensible by the positivists, who must eventually refer it to the subjective category—mental classification. The end accomplished by the positivists is exactly the opposite of their aim, which is to keep science empirical and clear of metaphysics. The result is deadening to all scientific advance.

THE REALIST VIEW

Mentalism was unsatisfactory to the scientists because, although it allowed objective reality to the objects of scientific investigation, it denied reality to phenomena and thus seemed to negate the validity of empiricism. Positivism was unsatisfactory to the scientists for the opposite reason, namely, because although it allowed reality to the phenomena observed, and thus to empiricism, it denied reality to the objective physical world, and thus seemed to negate the scientific search for the real, making its discoveries at last a subjective affair.

Among modern scientists there is a group whose theory of science is neither mentalist nor positivist but who believes, on the contrary, that the concepts of science refer to real conditions, that causality holds in the universe, and that therefore there is such a thing as law independent of our mental generalizations. The present gaps in detecting causality in sub-microscopic regions are attributed by them to ignorance of the factors involved and not to a basic indeterminism. Neither do they make the attempt of Eddington and Heisenberg to generalize from the sub-microscopic level to the macroscopic level, e.g. to prove or disprove free will. To quote Einstein,

> The belief in an external world independent of the perceiving subject is the basis of all natural science.[31]

But for Einstein this reality is not for ever hidden from view but can be known to the human mind, which grasps it through mathematical concepts.

> In a certain sense, therefore, I hold it true that pure thought can grasp reality, as the ancients dreamed.[32]

Max Planck, the discoverer of the quantum, agrees with Einstein in rejecting positivism and holding fast to the validity of the principle of causality as based upon an independent and real physical world. Even such an extreme example as Heisenberg's Principle of Indeterminacy, which has been used by philosophers of science to prove the non-existence of causality, is seen by Planck to be fundamentally causalistic. Regarding this principle, he says,

> Here the causal principle is not applicable. That is to say, we cannot estimate simultaneously both the velocity and position in space-time of a particle and say where it will be a moment hence. But this does not mean that the causal sequence is not actually verified objectively. It means that we cannot detect its operation. . . .[33]

And in regard to the positivist position, Planck is very strenuous in his denial; pointing out that science is concerned neither with the accidental, the contingent, nor the observable, i.e. not with sensations but with the reality which can be found by their help.

[31] *The World as I See It* (New York, 1934, Covici-Friede), p. 60.
[32] Ibid., p. 37.
[33] Planck, *Where Is Science Going?* p. 33 (George Allen & Unwin Ltd.).

That we do not construct the external world to suit our own ends in the pursuit of science, but that *vice versa* the external world forces itself upon our recognition with its own elemental power, is a point which ought to be categorically asserted again and again in these positivistic times. From the fact that in studying the happenings of nature we strive to eliminate the contingent and accidental and to come finally to what is essential and necessary, it is clear that we always look for the basic thing behind the dependent thing, for what is absolute behind what is relative, for the reality behind the appearance and for what abides behind what is transitory. In my opinion, this is characteristic not only of physical science but of all science.[34]

Not only is this understanding of science recognized by a few physicists, but at least one biological scientist states the same position unequivocally.

From the things encountered in the material world, whether atoms or stars, rocks or clouds, steel or water, certain qualities, such as weight and spatial dimensions, have been abstracted. These abstractions, and not the concrete facts, are the matter of scientific reasoning. The observation of objects constitutes only a lower form of science, the descriptive form. Descriptive science classifies phenomena. But the unchanging relations between variable quantities—that is, the natural laws, only appear when science becomes more abstract.[35]

This version of empiricism in science is not shared at present by many scientists. Most scientists prefer the positivistic point of view, which we have been criticizing. But even with Planck, Einstein, and Carrel the rejection

[34] Planck, *Where is Science Going?* p. 198.
[35] Alexis Carrel, *Man the Unknown*, pp. 1 and 2.

of positivism and the assertion of the reality of the entities of science is based upon happy intuitions and is more of a hope and a faith than a demonstrable belief. There is therefore some force to the point made by Eddington[36] that the present stage of physical science leads neither to an acceptance nor to a rejection of causality, and that therefore it is held by these men as a pure theory and cannot employ present-day physics as a basis for its proof.

'Happy intuitions' are not enough. The theory of science must be understood by the scientists abstractly and theoretically, in a form as universally acceptable as the findings of science itself.

We have already pointed out that the theory of science must lie outside the scientific field proper, and that one cannot make use of scientific findings to prove the theory by which such findings can be connected up with the rest of existence. The reality of the physical world and the existence of causality are thus not questions which can be resolved by the mere appeal to physics or to any other special science. Recourse must be had to philosophy.

The history of science reveals that the practice of science has not been at one with the theory. The fact that reason and experiment have both been employed wherever valid science has taken root may be contrasted with the fact that throughout the history of modern science scientists have unfortunately believed these two principles to be opposed. They have clung to empiricism for fear of going off into metaphysical quiddities. The refutation of positivism is easy, but the true definition of

[36] See Eddington, *New Pathways in Science*, especially p. 297 ff.

the place of empiricism in science requires more. It requires an analysis of logic and empiricism *as practised* in science, to demonstrate their essential reconcilability, and thus give rational justification to what is now only a hope and a faith. In the next chapters we shall turn to the fulfilment of this task.

CHAPTER V

NATURE OF THE FIELD OF SCIENTIFIC INVESTIGATION

For modern scientists, as for Plato, IDEAS are the sole reality.

A. CARREL

WE have come to the end of our brief survey of the history of empiricism, in practice and theory. It has been seen that the controversy over the question of empiricism centres around a single comprehensive issue. We shall now have to separate this issue from the various historical figures who have taken sides with regard to it. This will entail leaving history and concentrating upon the abstract problem.

WITH WHAT IS THE CONTROVERSY CONCERNED?

The various schools and traditions whose doctrines we have exhibited are in effect so many answers to one question, namely, what is the true subject-matter of science? Science itself can restrict its abstract interest to the problem of method, whether this be logical or experimental. But philosophies of science must be concerned with something more than method. They must be concerned with subject-matter. Even those abstract speculators who suppose that their preoccupation is only with method are mistaken. For what is a method, if not a step toward something else, a means of achieving an end? Thus science is more than method, even though

strict scientific analysis may not have to take this fact into consideration.

Thus the three schools which we have examined, the positivists, the mentalists, and the realists, all primarily direct their attention to the nature of the field of scientific inquiry. The positivists believe that they can make the method of science itself into the subject-matter of science. But even this is an attempt to define the subject-matter. The mentalists find the nature of the scientific subject-matter[1] in mysterious noumena, an unknowable something lying behind the field of sensory phenomena. The realists find the nature of the scientific field in a directly knowable set of relations, which phenomena only exemplify. Let us take some familiar entity of science and show how each school would regard it.

The physical law of action and reaction is a scientific entity. The question then is: what is the status of its reality? To this question the answer of each of three schools is different. For the positivists, the reality of this law resides only in the actual or observed phenomena. As to the reality of the law itself, they would deny its existence as an independent entity and claim for it the status of a mental concept. For the mentalists, the reality of this law resides in its existence as a mental concept derived from real but unknowable objective conditions of nature. For the realists, the reality of this law resides in real and knowable objective conditions of nature. The law is thus a reality independent of both subject and object, independent of the subject since existing

[1] The mentalists seem to have confined their remarks to the science of physics and the nature of the physical world.

without its knowledge, and independent of the phenomena because existing without such exemplification. Thus the understanding of such a 'law' or scientific entity as the law of action and reaction differs in all three cases.

One clear fact must be admitted at this point. This is that physicists, though they hold different philosophical views concerning the reality of the physical subject-matter, seem to function equally well as physicists. For instance, Heisenberg, Eddington, and Planck seem to have no disagreements over each other's work as physicists. Their disagreement comes only with the interpretation of their work. Does this mean, then, that the question of the reality of the scientific subject-matter is meaningless? Certainly it does not seem to have affected the procedure of the science of physics. It is just this point which makes the scientists so professionally disdainful of metaphysics.

To this question of what difference does it make there are many answers. First of all, procedure does follow from philosophy. When the physicists hold one philosophy and practise the procedure that would follow from another philosophy, this merely means that they are not holding the philosophy they think they are holding. Newton could not possibly have leaped from terrestrial to celestial mechanics without the belief in the universality of natural law, which certainly is not to be found in any analysis of the motions of bodies. From a purely analytic point of view, there is no warrant for such a theory. Again, without a belief in the continuity of natural phenomena, no one would ever have tried to find the proper equations for the cicatrization of wounds.

In other words, analysis is not the whole of scientific procedure, although nothing unanalysed can be called scientific.

Plainly any science must start by seeking isolatable systems to be analysed, and these systems cannot be found by analysis. Granting it to be true that the analysis is not affected by the interpretation put upon the meaning of the isolated system, it is still true that without some meaning for the total system, no new system could be found. Certainly the anatomical analysis of the spleen is unaffected by the function of the spleen in the animal constitution; but until the relation of the spleen to the whole organism is better understood, this analysis will not only be largely meaningless but also undirected. Thus what does not affect analysis directly does affect the understanding of that analysis and, indirectly, the analysis itself. An example may be taken from common experience. A chair could be analysed without the analyst knowing its use or purpose. But certainly such analysis would be entirely without value and without interpretation. What purpose would be served by specifying the weight-bearing properties of the legs unless in the light of the use of the whole chair?

If physicists came to the conclusion that analysis of systems *now known* is the whole of physical science, there would be no more systems to analyse. In other words, with the wrong philosophy, science cannot keep on developing, but must stagnate. In so far as physical science has followed the wrong philosophy, it probably has, despite its brilliant success in the past, been somewhat retarded. It will certainly be brought to a halt in the

future unless its first principles are straightened out. About other sciences we can speak with more confidence. The far less successful biological sciences owe their partial failure and retardation to a timidity of theory which lays the injunction upon scientists only to analyse. The positivistic or 'empirical' creed of the social sciences has strangled them in gestation. So vicious has been the effect of the wrong philosophy in the social sciences that, at least in some quarters, even the possibility of exact social science is denied.

Besides the crippling of science itself, there is the large and unavoidable question of the place of science in the scheme of things. For instance, what of science with regard to society? Surely on the answer to this question the future of science will largely depend. And unless science can answer the question as to what it is concerned with, it may be challenged by society and prove unable to defend itself. Finally, the scientists themselves are something more than scientists: they are human beings who require some answer to the question of what they are spending their lives doing. In the course of every laboratory day, the question is bound to occur to the scientist of the meaning of his activity, even though he dismiss such considerations as irrelevant to the immediate business at hand. But the question cannot be dismissed for ever and is bound to recur to every human being, until he answer it at least to his own satisfaction. If the answer be that there is no answer, i.e. that it is a meaningless business, he could not go on in a wholehearted way. It is at least arguable that the great advance in physical science in the past three hundred years has

been activated by the belief that this is the best way to find out the nature of reality.

We may conclude by saying that scientific method depends upon the philosophy of science. The future of science depends upon the philosophy it adopts. Therefore the sooner the scientists become aware of this condition, the better it will be for the welfare and development of science.

THE INQUIRY INTO SCIENTIFIC OBJECTS

We have seen that the philosophical problem of the nature of science cannot be dodged by science. This problem is the nature of the objects with which scientific analysis works. Let us attempt to determine what their nature is by examining them under their various names. In attacking this problem no mystical or complex metaphysical theory or discussion need be introduced. The nature of scientific objects must be, like the nature of anything else, defined by what is implied by them. The technique of philosophical analysis does not differ essentially from that of scientific analysis, though it operate from a different level.

Scientific objects are known variously, and sometimes interchangeably, as entities (e.g. a molecule), concepts (e.g. entropy), processes (e.g. radio-active disintegration), events (e.g. an electromagnetic force field), and laws (e.g. Avogadro's Law). These may all be described as scientific objects. It is at once obvious that some of the terms are interchangeable. In order to examine their nature let us start by finding out and discarding what they are not. Are scientific objects mental? No, since by

mental is meant something which depends for its existence exclusively upon the mind. All our scientific objects give every evidence of existing, and exerting influence, indifferently as to whether they are perceived or thought about or not. Thus it would be idle to call them mental. The conditions which are described as entropy continue whether there is consciousness of them or not, and indeed we are assured by the astronomers that entropy will go on long after animal life has become impossible on a rapidly cooling planet.

The same independence of knowledge holds for Avogadro's Law: under the same temperature and pressure, equal volumes of gases continue to have equal numbers of molecules, regardless of whether we know about this fact or not; and this condition will continue to prevail even if in the future it is forgotten. Perhaps the notion that scientific objects are mental has arisen from the recognition of the fact that in so far as these conditions are known they are known. But why confine this to scientific objects when the same is true of an elephant in the zoo? We have already shown that when scientific objects are dubbed mental, the implication is that they depend for their existence upon the mind, which is simply not true.[2] Thus the concept of entropy is mental

[2] If the old subjective argument be invoked that we cannot know anything about anything when we are not knowing it, and that therefore we cannot assume the existence of anything when we are not knowing it, the answer is that it is irrefutable but also undemonstrable. It is, moreover, incredible and fruitless. Whoever chooses to believe that radio-active disintegration ceases when it is not in any human consciousness, will have to take the same position with regard to the elephant.

in so far as it is a concept, but entropy in so far as it refers to conditions which are not mental. Similarly with the concept, elephant.

Mentalism, however, is generally put forth as a sort of objective mind-stuff theory. The 'stuff' of physics is said to consist of mind, perhaps thoughts, in the mind of God. But does this theory help any more than the other to explain what scientific objects are? Let us accept it and see where it leads. The mind-stuff called sulphuric acid analyses into the mind-stuffs called hydrogen, oxygen, and sulphur, which in turn analyse into mind-stuffs called electrons, protons, etc. It is evident from this analysis that the term mind-stuff is being carried for nothing, and since it appears on both sides of each equation, can be cancelled out with no loss to the knowledge of what is involved.[3] Our knowledge of sulphuric acid is neither helped nor retarded by the term mind-stuff. An explanation which makes no difference is not an explanation but a restatement, more or loss clumsy, of the original problem. Unless differentiae can be shown to arise from the distinctions made, they are not worth making. Thus to say that the nature of the physical world is mental in either the subjective or objective sense of the term, is to use 'mental' to describe everything, and therefore to rob it of any sense it may have. It is also to leave the problem of the nature of scientific objects just where it was.

[3] Let mG = the mind of God. Then

$$mG\,H_2SO_4 \rightarrow mG\,SO_3 + mG\,H_2O$$

It is obvious that dividing through by mG will give an equation which yields the same result.

It has been shown that scientific objects are not, in the usual sense of the term, mental; and if called mental in the unusual sense of mind-stuff, the proposition is nugatory. We have now to consider whether scientific objects are actual. By 'actual' is meant phenomena which are experienced, with all their affects and values. In other words, are the objects of science to be wholly identified with the common-sense objects of our daily observation, such as red apples, sunsets, parades, water, turtles? Plainly, science is not primarily concerned with such common-sense objects, and does not rest content with them. Science always abstracts certain qualities when it experiments with common-sense objects. Thus it was not the apple but the apple's fall which interested Newton; and it is not the wetness of water or its potability which interests the chemist.

But the inquiry of science goes beyond even the abstractions of qualities from particular objects. For instance, it is not even the apple's fall which is ultimately interesting to the scientist who works with mechanics, but the relations of mass, distance, and time, which the fall of the apple exemplifies. It is not the particular length of a bar of metal which concerns the physicist, but relative dimensions. The same is true of biology, though not so obviously. The zoologist who examines the relation of the temperature of turtle blood to turtle heart-beat is not the least concerned with the awkwardness of the turtle or the edibility of turtle meat or the decorative value of the shell. In other words, the particular common-sense turtle means nothing to the zoologist, who is employing certain abstractions from a

particular turtle only because he believes on sufficient evidence that he has got hold of a fair sample of heart-beat and temperature of the species, turtle. Thus again science proceeds from the common-sense phenomena to the abstractions of certain qualities from such phenomena, to generalizations about the relations of such abstract qualities, or to what are called laws.

Those qualities which science abstracts tend to become those which are commensurable. This is the ideal of every science, but at early stages qualitative differentiation is abstracted. In general, we may say that scientific abstractions proceed from qualities to quantities.

At this stage we reach entities or laws or processes or concepts which can hardly be said to be phenomena, though they be reached in and through phenomena or by abstraction from phenomena—abstractions many times abstracted. This is why mere description or classification is the most rudimentary form of exact study; it stops at the first stage of abstraction. We arrive at the conclusion that scientific objects are not actual, even when they are exemplified in actuality. The scientific molecule is not identical with the actual molecule, even admitting that such an exemplification could be demonstrated. Entropy is not understood by science as the actual disbursement of energy; degradation goes on at any moment, but is only an exemplification of entropy. Radio-active disintegration may be observed to take place over a period in radium, uranium, etc., but the process is not confined to detectable occurrences. Electromagnetic fields are studied independently of actual fields set up, e.g. mathematically. And Avogadro's Law is merely

exemplified by any gas under pressure, and is a statement of conditions which do not become dissipated with the dissipation of the gas. These are the objects of science, and as such are hidden from common observation as they occur. They are empirical because they are detectable in and through actuality by trained observers; they are non-sensory and have no dependence upon phenomena, i.e. phenomena depend upon them. It is for this reason that experiment is used in science to prove or disprove theories or laws.

SCIENTIFIC OBJECTS ARE FUNCTIONS

We have seen that scientific objects are essentially neither mental nor actual, and that the end of scientific investigation concerns the finding of abstract relations. It proceeds from phenomena to abstractions from phenomena, to abstractions concerning relations between abstractions. The relations between abstractions can be best understood as representing constant functions, the invariant relations between variable quantities. Functions are therefore the objects of scientific inquiry. They are the scientific objects. And this is seen as soon as we discard the pictorial or mythological tags by which they are ordinarily represented. How can we best understand without reference to the formulations of science what a function is? Function is defined[4] as "that power of acting in a specific way which appertains to a thing by virtue of its special constitution." The function of anything, then, is its necessary relation to something else. It is what is essentially true about a thing so long as it is a thing.

[4] *The Century Dictionary.*

If, for example, we say that the function of a lead-pencil is to write in a certain way on paper, we are saying two things: (1) that it must be composed of something capable of performing this function; and (2) that it is potentially capable of acting in a certain way. Thus however variable may be the constitution of a lead-pencil, and however variable its use, the function between the constitution and the use is constant and necessary.

The functions of a right-angled triangle are studied in trigonometry. They are the necessary conditions to which any right-angled triangle must conform to be a right-angled triangle.

$$\text{Sin } A = \frac{\text{Leg opposite } \angle A}{\text{Hypotenuse}}$$

is a statement of an invariant relation between variable quantities, which lays no restrictions upon the size of the triangle nor the degree (within limits) of the angle A. It is to be noted that this is not an accounting of anything actual but an abstract condition to which any actual triangle must answer. In other words, it is the special constitution of a triangle by which it can be operated in a certain way.

The definition of scientific objects as functions must be noted to include the various names given to scientific objects: entities, concepts, processes, events, laws. Now, an entity or a thing is defined by its function, as we saw above. A match, a street car, copper sulphate, velocity, all these are defined by their function, i.e. by the way they can act. And we have seen that this is the determining

fact in their constitution. Thus we always mean by an entity (in science or out) a function.

It may not be so clear that a concept is a function, but such is the case. A concept is the mental recognition of a function which is not mental. Thus the concept, table, refers not to a particular table but to any table, i.e. to the function, table. Similarly, democracy refers to a possible condition or function and not to anything actual. The mental image by which the mind grasps ideas or functions is not itself the concept. Thus the word, beefsteak, may bring up in many minds different images, visual, auditory, olfactory, or gustatory or many of these; but that to which the image refers, i.e. the concept, beefsteak, is the same. When a concept is spoken of in science, it is obviously not the mental aspect of it which is meant, but rather that to which the mental refers. And this is identical with the scientific entity.

That a process is also a function becomes evident from an examination of process. A process is a course of events which is separable from the sum-total of happenings. It is only separable on the basis of its special manner of procedure. Thus what defines any certain process is not events so much as the certain form they take. But this form is a function in operation. The 'processing' of wood pulp into rayon is obviously a function, since it is defined primarily by the end in view, and secondarily by the particular events which are means to that end. In other words, processes are defined by the end toward which they are directed. And this determines the events which lead up to that end. The process of electrolysis is likewise a function, inasmuch as it is defined by the breaking

down of water into oxygen and hydrogen, and secondarily, by the electro-chemical events which bring this about.

It is apparent, however, that when a process is referred to, reference is not made to any particular actual process but rather to certain possibility of actual process, so that the process is not confined to place or date. In this light it will be seen that a process is a function. It is also to be noted that there is no logical distinction between a process and an entity; one is merely viewing a function as a possibility of action (entity), and the other is viewing a function as in action (process). 'Entity' is function as potential; 'process' is function as kinetic. The distinction between these can be more clearly understood when we note that processes are constantly spoken of as entities. The term, hypostatization, or reification, means the viewing of a process as an entity. But this is no figure of speech, since whenever we talk of an entity we also mean a process, and *vice versa*. For instance, a mouse and a mountain are entities; but they are equally processes, since that which makes their functions what they are is in a constant state of change and motion. Mice grow and die; mountains constantly erode. And the parts which make up these entities are always in flux: cells, molecules, atoms, etc. All actual things are in process, and it is the process itself which shows enough uniformity to be isolated and spoken of as persistent. When this is done, we have hypostatized the process into an entity.

Obviously, an event is a function since it answers to the same definition as a process. No event can be called

an event without defining its purpose or end or direction. Thus whatever we have said about process applies equally to event.

Of our group of scientific objects, it remains now only to show that a law is a function. A law is a necessary uniformity to which relevant processes and events must conform. It may therefore be called a general function which conditions particular functions, just as Ohm's Law is a general function conditioning the particular function of a given electrical current in a given wire. $\frac{V}{I} = R$, where V is the potential (volts), and I the current (amperes) and R the resistance (ohms). A law, then, is the notation for a general function which governs particular functions inexorably, and is therefore a statement of fact, which is just as objective as a mouse or a mountain or electrolysis or entropy. It is observable in the same way, namely, in and through experience, and it is conceivable in the same way, namely by means of words, symbols, or images. It is equally with them not actual, being the governing function for actuality, i.e. it can be actualized or even exemplified in actuality. Thus a law can be called a scientific object: an entity, a concept, a process or a series of events.

We have seen that the best and most embracing term to cover all of these terms is that of function, which may be taken to mean what it means in ordinary discourse: possibility of certain action or a special constitution by which it enjoys a certain possibility of action; or which may be taken to mean what it means in mathematics: an invariant relation between variables. Thus the

scientific objects—the subject matter of science—consist in a world of real relations, expressible by functions.[5]

FUNCTIONS IN THE VARIOUS SCIENCES

Let us take examples from each of the various sciences in order to show that their subject-matter is always that of abstract relations or functions and never that of anything actual. This is obvious in the more abstractive sciences, but perhaps it should be illustrated.

In analytic geometry, $x^2 + y^2 = r^2$ (for rectangular co-ordinates, x and y) is the equation of the circle. But obviously this equation does not represent any given circle or any actual circle, but rather the conditions which any actual circle must satisfy.

In physics 'density' is the mass per unit volume of a substance, i.e. it is the relation between mass, expressed in units, and volume, expressed in units, and is not to be understood as an actual 'quality' of any actual thing in the sense of being actually separable from it.

In astronomy, 'planet' does not refer to a certain actual body of matter in all its sensible effects. It refers to the function of any body, except a comet or meteoroid, that revolves about the sun. The actual bodies named Venus, Mars, Saturn, etc., perform this function; and in so far as they do they are planets. Should these bodies, from some cause or other, cease to so revolve, they might continue to be actual bodies but they would

[5] Since mathematical symbols are the most abstract (i.e. non-actual) expressions which can be found to represent relations, it follows that mathematical formulations of functions become the true goal of all science.

certainly not be planets. The term planet refers to the function and not to the actualization of it. Similarly, if new bodies are discovered to revolve about the sun, they would be rightly termed planets in so far as they fulfil this function.

In chemistry, 'valence' is defined as the ability of an element to combine with another element. This does not refer to any given actual quality of an element, in the sense of a property which can be actually separated. It is a function of the combination or relation between elements. It is true that it could be determined by the number of free electrons on the outer layer, but this does not affect the logical fact that valence is to be defined only in terms of relations between elements.

In zoology, 'marsupial' is defined as a mammal having a pouch in which the young are carried. Plainly this does not describe any actual opossum or kangaroo except in so far as they exemplify this function. A female kangaroo born without a pouch would be a kangaroo but not a marsupial.

In botany, 'chloroplast' is defined as a plastid containing chlorophyll, developed only in cells exposed to the light. Obviously we have in chloroplast a function between certain plastids and light, which is only exemplified in actuality when this function is satisfied. Thus it cannot properly be identified with any actual plant which may or may not exhibit it.

In economics, 'economic man' is defined as that man whose activities are entirely concerned with the economic level. Certainly no such actual man exists, since although every man is sometimes and somewhat concerned with

economic activity, no man is altogether so concerned. But the fact that the economic man is non-actual does not make the abstraction, the 'economic man,' an unreality. Its reality lies in its functional nature which actual men may or may not share in more or less degree. Thus once again 'economic man' refers to abstract relation or function. Similarly the 'bourgeois class' does not refer to any actual member of this economic class who may at the same time be or become in other ways members of the proletarian or capitalist class. It therefore refers to a certain function in society, which varying members to some extent fulfil at different times.

In sociology, 'criminality' is defined in terms of the breaking of certain established laws of society. Thus it is not properly applicable as a fixed attribute of any actual person. There is no criminal type *per se* but only persons who participate more or less in such anti-social behaviour, i.e. in the particular social (or rather anti-social) function.

In politics, 'parliamentarianism' is defined as that form of government in which the State confers upon the legislature (elected by popular vote) the complete control of the administration of law. Probably no actual State has ever been entirely governed in this way, yet parliamentarianism applies to some states in so far as they partially fulfil this function.

We have seen that the subject-matter of every science is a set of functions which are strictly non-actual, being exemplified more or less in actuality, but never identifiable altogether with it. They are the forms or relations which actuality must follow and by which actuality is understandable. When these functions or abstractions are

known, they are properly called concepts; but they are not created by the mind nor do they depend upon it for their functions to be fulfilled, in the sense of having no existence when not cognized. The subject-matter of science is therefore strictly abstract and non-picturable, and whenever pictured is a convenience which finally gets in the way by being misleading. Thus the symbols of mathematics are the best scientific representation.

ARE SCIENTIFIC OBJECTS EMPIRICAL?

From the above exposition of the nature of scientific objects, we can perhaps see why the mentalistic and the operational interpretations arose and how they went astray. The mentalists correctly comprehended the fact that scientific objects are not to be strictly identified with actuals, and that scientific functions are most easily manipulated in their mathematical formulations. They understood very well that the world picture of science could be put without distortion only into mathematical terms. But once having decided that scientific objects are not actual, this school declared them mental, presumably because they are conceivable by the mind.

On the other hand, the operationalists, striving to save the reality of scientific objects, tried to hold on to actuality. They went half-way in the understanding of the fact that scientific objects are functions, i.e. that scientific functions are actually operable. But the existence of functions as such when not in process or operation was denied. Thus scientific functions when not in dynamic relation, were supposed to be only summaries of real dynamic relations, and thus concepts in the mind.

We may conclude by pointing out that both mentalists and operationalists are partly right and mostly wrong in their understanding of the nature of scientific objects. They are non-actual, they are operated in actuality, they are conceivable; but they are also real, abstract, and non-mental.

Where, then, has our inquiry into the nature of scientific objects led in regard to the main thesis of this work: the nature of empiricism? In other words, what is the relation between empiricism and the objects of science as defined, namely, as functions? On the one hand, can we assert that the actual objects of ordinary observation are not empirical? Certainly we cannot. Apples, horses, dances, and storms are empirical; they are also actual. But on the other hand, can we throw out of the category of the empirical those abstract scientific entities which we have been discussing, such as valence, density, radio-active disintegration, etc.? Obviously to do so would be to destroy the claim of every science to be empirical. This is tantamount to destroying the idea of science itself. Assuredly empiricism has some close connection with actuality but is not to be understood as being identical with it.

Ultimately empiricism does rest upon the observation of actuality. But the understanding of observation as the mere run of experience tells us nothing. At the lowest level of observation, patterns are discovered within actuality which are not strictly sensory. For example, that a chair or a table has the function that it does is not revealed by sensory analysis or observation unintegrated. Thus observation is shot through with inferences

of function, which finally become so familiarly accepted that functions are thought to be sensed. For instance, the average city dweller 'sees' the black instrument on his table as a telephone, but to one ignorant of the use and purpose of the telephone it would only be a black object of a certain shape to which he could assign no meaning. But that the function of an ordinary object is not sensory *per se* surely does not mean that it is not empirical, since its function is demonstrable in experience. If this is the case, the term, empirical, can and must be applied to any function which is either observable in operation or which can be inferred by observable processes in nature.

Empirical entities do not stop here, since the inferences from agreed on hypotheses may be verified by reference to the body of agreement. Thus that which was not empirical can become empirical, e.g. molecules which were once only hypothetical, are now empirical. They are empirical even though they are not yet visible through the microscope. The empirical field is not a fixed affair but is made comprehensive according to the body of agreement. The law of action and reaction always existed and always will, but became through scientific recognition an empirical fact. In other words, we have discovered that empiricism is not a quality of the objective world but a function of scientific inquiry.

In this chapter we have examined the nature of scientific objects. In the next chapter we shall make an analysis of scientific method or the method of empiricism in science.

CHAPTER VI

THE METHOD OF EMPIRICISM

I hope I shall not shock the experimental physicists too much if I add that it is also a good rule not to put over-much confidence in the observational results that are put forward until they have been confirmed by theory.

A. S. EDDINGTON

THE BRUTE FAITH IN THE GIVEN

WE have arrived at the conclusion that the entities of science are not *per se* either empirical or non-empirical. Empiricism concerns the status of scientific knowledge. We must now make an analysis of the empirical method as employed in science, and in order to accomplish this task we must examine empiricism at the level where it is not exclusively scientific, even below the common-sense level, at the barest giveness of sense experience.

There is an element in all experience which is insusceptible of further analysis. This element cannot be rationalized any further than to state that it *is* for sense experience. Such brute facts are those which thrust themselves upon us without any explanation. Nothing so sophisticated as a lump of sugar or a book or a carnation is meant. We mean the sight of redness, the smell of honeysuckle, the touch of a stone, the sound of a bell, the taste of salt. For all these cases, the sources which convey the sensations must be dropped. The bruteness concerns the sensation itself, and not any judgment about its source or cause, or even position of occurrence in

time and space. It must also be noted that the existence of these brute facts cannot be proved or explained in any final way. In other words, these presentations are accepted on faith, agreed upon roughly by convention, and regarded as merely 'given.' As such they are the irreducible building blocks on which all experience is mounted, and therefore the basis on which science and even logic ultimately rest. On the identity of these presentations and their differences, all rationality relies. Such facts constitute the final court of appeal for both logic and empiricism. Nevertheless, the rational structure has to do with differences and relations between such things which in themselves tell us nothing about their intrinsicness.

The pure bruteness of experience, as we have set it forth, has never been entertained by anyone. There is no content without form in anything experienced; no sensation has ever taken place without some kind of minimal judgment. We cannot see red without the idea of redness or the understanding of something red. A sound or an odour is at least given spatial location, however vague, simultaneous with the sensation itself. These brute facts, together with judgments about them, constitute individual experience and the world of social agreement. Inasmuch as there is no purely brute experience, perception is made possible by an understanding of the relations between brute facts. Thus the cubeness of a cube is not a fact which can be experienced as such, since what is seen or felt is always a surface. A cube is, then, an inference from the relations of sensations of brute facts. But certainly a cube is part of the social

world, and as such, an empirical fact. The sciences largely concern this social world. However, this statement must be modified in two important respects. The science of psychology, for example, may take as its field of study the private order of experience—dreams, phantasms, and images. And all the developed physical sciences, though they start with the world of social agreement, suppose the existence of a natural world of which social agreement covers only a small part.

We have seen that brute facts underlie empiricism, but that no empirical facts, even at the common-sense level, are purely sensory. We might also infer from the above that the data which constitute empirical subject-matter for one science would not be empirical for another. For instance, the pink rats seen in *delirium tremens* are not empirical from the point of view of zoology. But the same bit of evidence is accepted as empirical by abnormal psychology. So far it would appear that the test of empirical subject-matter is a function of agreement among those qualified to judge. But this is not enough. Social agreement is still undercut by the brute facts of sense experience, which are 'agreed' upon, without choice and of necessity. Science does often contradict the judgments of common sense which rest upon experience, but it cannot ultimately contradict the senses themselves. The abstractions of science leave sense experience so far behind that they do not seem ever to have started from it. Nevertheless, the structure has been built *ad seriatim* from brute facts upward, and must be demonstrably non-contradictory to them. Science, therefore, does start from sense experience.

ABSTRACT CHARACTER OF COMMON EXPERIENCE

It is not ordinarily recognized how much beside sense experience enters into the world of common agreement. We have only to mention such non-sensory facts as time, space, causality, and chance, to show that without such categories sense experience does not make 'sense.' It need hardly be urged that we do not directly experience time, space, causality, or chance. These are constructions of brute facts, yet they are facts just as hard and fast as the evidences of sense experience themselves. And unless one assumes the philosophy of radical empiricism, they are accepted as such.

This necessity of categorization, with its universal and implicit acceptance, is well illustrated by the existence of what is called history. History understood as a succession of actual events which have happened is nothing anyone would consider to be history. Particular events must be shown to have some kind of direction or meaning before history is admitted. The direction and meaning of events are notoriously judgments. But even if we admit that the mere succession of actual events is history, such a chronicle already presupposes a fixed time-order, which is surely never sensed. And as we have shown, even the observation of these events as they occur cannot be made without non-sensory inference. The movements of horses and men is already an inference from brute sensations. But the movements of horses and men can only be called a 'battle' by inference. However, no history stops with even such judgments, but goes on to infer results and causes and to link these up with such

abstract facts as 'revolution,' 'increasing nationalization,' the 'decline of the West,' etc. Despite the fact that historians will largely disagree on the speculative truth of such broad movements, speculation is always demanded, and all historians are in agreement concerning what they call the 'facts,' i.e. rudimentary constructions (less daring inferences).

From recorded history of the more remote past, we may turn to the daily affairs of common experience. Here we can see also that abstractions play the part of accepted fact in the understanding of brute experience. For instance, no one doubts that there is a political 'sphere' or an economic 'scene.' Indeed, most of our discussions about 'what is going on in the world' take place in terms of non-sensory abstractions. Will the United States Government become more or less centralized? Will the stock market recover? Is agriculture to become industrialized? Is communism in Russia moving to the right? Every one of these questions is framed almost altogether in abstract terms, terms many times removed from the sensory. Yet they have the validity and reality of stubborn hard fact. No one doubts, for instance, that agriculture is a real thing though no one can sense agriculture. The operations of the stock market are to many persons the most real of all realities; yet who has ever sensed a stock market operation? The best that can be seen are brokers walking to and fro and writing on slips of paper, or ticker tape, or chalk marks; but certainly these are not equivalent to the fact of the stock market.

We have seen that the empirical world we live in is shot through with, and indeed mostly composed of,

non-sensory and abstractive facts. To understand this world to some extent is the test of sanity. The insane man is not the man who lacks his five senses (indeed, many sane persons lack one or more senses, e.g. no one would call Helen Keller insane). What the insane man lacks is the ability to make abstractions from his sense experience in a way which agrees with the abstractions of his fellows. Hence it is upon the quality of abstractions and not upon the quality of sense experience that sanity depends. The insane are said to live in an unreal world, e.g. they cannot understand social realities, and social realities are abstractions. Nobody acts as though he truly doubted that social facts are real and that abstractions are empirical.

Having seen how the actuality of common experience is compounded of abstractions far in excess of the sensory, let us now turn to science to see how the process of abstraction is carried further. Just as common experience infers from pure sensation, science starts from the facts of common experience and makes inferences from these to arrive at its peculiar abstractions. True science does not start until abstractions are made from actuality. Science begins by abstracting from actuality, past and present, and thus from place and date. It therefore follows that science does not deal with unique particulars; indeed, it gets away from sense experience altogether, even though the terms which it uses to express its meaning have perforce a certain sensible aspect. These abstractions from actuality are the first empirical entities of science, non-sensory. Thereafter science deals with these abstractions as though they were given, and no further

with the sensory facts on which they ultimately rest. Indeed, for purposes of procedure, these abstractions *are* the 'given' of science.

PROCEDURE OF SCIENTIFIC ABSTRACTION

The subject-matter of science is removed from actuality, to which it returns only to make sure that its entities are still empirical, i.e. that they check with sensory fact. We have seen in the last chapter that the subject-matter of all the sciences is functions. We have seen in the last section how these functions are arrived at by abstracting from actuality. Thus the realm of science is the real but non-actual realm of functions, and each science deals with a set of functions abstracted by means of some canon or level of analysis. For instance, physics deals with the space-time functions of actuality abstracted from actuality, and biology deals with organizational functions of the living physical organism abstracted from those actual living organisms, etc. In this realm of functions the categories of actuality have no application. Functions do not change, since they are the unchanging expressions of change between actuals. Thus functions are timeless. Again, the category of space has no application to functions, since the relation between things in space has no location. Functions have no affective value; not only are they non-picturable and non-sensory, but neither do they have the value connotations of good, bad, ugly or beautiful, worthy or unworthy. Science for the purposes of science is *wertfreiheit*.[1]

[1] This term, coined by Max Weber, is translated by Brock as the "necessity of abstaining from valuations in science." See Werner Brock, *An Introduction to Contemporary German Philosophy*, p. 27.

When science reaches its abstractions from actuality, it does not stop with them, nor does it simply accumulate a set of these abstractions, largely unrelated. It rather endeavours to build a system of such functions by (*a*) finding through analysis the implication of those functions, and (*b*) abstracting from those functions and arriving by induction at functions of greater generality which include the lesser as special cases but do not replace them.

An example of (*a*), the finding through analysis of the implications of functions, may be taken from the fact that Priestley's discovery of oxygen is a specific implication of the more general function of chemical element. Specificity in the finding of less general subsidiary functions is as essential for scientific knowledge as is the discovery of the more general. But specificity in this sense is not to be confused, as it so often is, with unique individuality. 'Oxygen,' as a scientific entity, is no more actual than is 'chemical element,' but it is more specific. Both have to deal with possibilities.

An example of (*b*), the process of abstracting from abstractions, may be taken from medical science. The first abstraction in regard to immunity was made from actual cases of special diseases, e.g. immunity from diphtheria, from smallpox, and then abstracted as the principle of immunization, regardles of any particular disease. Another example of the process of abstracting from abstractions may be taken from the differential calculus. Rate of change is certainly an abstraction; but we can abstract from it to the second rate of change (the rate of acceleration). This second derivative is the rate of a rate, and thus a further level of abstraction.

As the empirical test of the first abstractions of science is actuality or demonstration, just so the empirical test of the higher abstractions arrived at by induction are the first scientific abstractions already tested. It is true that in most cases the second level of abstractions can be tested directly against actuality, i.e. experimentally. But this is not the prime test. The prime test is against the first level of abstraction. Nor does science necessarily stop here, but can go on indefinitely; and in each case the empirical test can be either against the last level of abstraction or against any level or against actuality itself.

A system erected in this way ultimately rests, as it must, on brute sensory fact. But the dependence is neither apparent in the higher levels nor necessarily remembered in the empirical check. The roof of a house does not seem to rest on the ground; nor does a builder fashion a roof with this thought in his mind, but rather to conform to the structure of the whole. Nevertheless, the roof rests on the joists, the joists on the uprights, the uprights on the foundation, and the foundation on the ground. The roof must, of course, rest finally on the ground, but it must also form with the rest of the house a self-consistent structure.

It is sometimes supposed that non-Euclidean geometry has no necessary connection with experience but is a purely formal science. Non-Euclidean geometry has its origin in the denial of the parallel postulate and the acceptance of certain others. But, of course, Euclidean geometry is an abstraction from the observed motions of rigid bodies, and therefore plainly empirical. Since non-Euclidean geometry is only once removed from the

empirical basis, it too is empirical in the same sense that all the abstractions of so-called applied mathematics are empirical. If Tom stands on John's shoulders and John stands on the ground, can it be said that because Tom no longer has any direct contact with the ground that he is independent of it? All sciences are empirical inasmuch as they directly or indirectly depend upon sensory fact, and all sciences are empirical in so far as they form self-consistent systems.

THE PRINCIPLE OF ECONOMY

However necessary the connection between empiricism and the sensory, more is needed for the empirical proof in science than demonstration by observed fact. Contradictory theories can be shown to agree with observation. A notorious case is the Ptolemaic and the Copernican systems which take into consideration sensory fact, on the basis of which they would still be valid. Nevertheless, the Ptolemaic system is no longer held to be an empirical fact of science, since it no longer agrees with the other inferences built up in modern astrophysics, with its telescopic and spectroscopic inferences. It must be noted that these newer theories are also based on observances and thus we have two theories in agreement with sensory fact yet mutually contradictory. The preference for the Copernican does not depend at all upon sensations, but upon its ability to embrace and form one system with new inferences and old laws.

Thus the first and main empirical test in science is that of self-consistency within the given system, i.e. the body of accepted theory. If a new theory meets this test, it then

rests directly upon older and accepted theories, and so *ad seriatim*, until it rests upon theories which fit the observed facts. Thus the consistency of a theory with a given system means *ipso facto* that it is dependent upon sensory fact. But something more is involved. One part of empiricism is the principle of economy, the admonition that no more explanation than is absolutely required be introduced. This is a variant of Occam's Razor, which states that entities must not be multiplied beyond necessity. Thus one theory which covers two separate groups of fact and theory is always preferable to two theories. And a theory which is addressed only to an isolated group of facts and has no relation to other theories is immediately suspect and never altogether accepted as empirical. This is what the scientists denounce and reject as *ad hoc theory*.

Einstein's general theory of relativity, so completely endorsed that it is already the empirical basis for further investigation, was largely accepted by physicists because it was able to embrace and agree with both the Newtonian theory of gravitation and inertia, and the new facts discovered since Newton, e.g. the failure to detect the ether drift.[2] The theory of relativity has supposedly been proved by three experimental tests: (1) the precession of

[2] Lorenz and Fitzgerald explained the null result of the Michelson–Morley experiment by supposing that motion through the ether altered the linear dimensions of bodies in a way which could be expressed mathematically. Here was an *ad hoc* theory which was supplanted by relativity, and the alleged 'conspiracy' to prevent the measurement of absolute motion was reformulated as a uniformity of nature in the principle of relativity, in a way to make absolute motion supererogatory.

the perihelion of Mercury, (2) eclipse photographs, and (3) the shift toward the red end of the spectrum in the companion of Sirius. All these experiments bore out Einstein's law to closer approximations than Newton's. However, the theory of relativity does not rest on these experiments but was proved before them, and has only been confirmed by them. The theory of relativity eventually is acceptable because of its consistency with the prevailing body of physical theory. For obviously many theories might be constructed to explain the results of these three experiments. But unless they agreed with the main body of physical theory, no physicist would give them an instant's consideration.

We have been exhibiting empiricism as the principle of economy. As such it is a cautionary measure and not strictly a method, not the leading principle of science, since by itself it does not constitute science, forming nothing new but holding down the new to conformity with the old and accepted. Without it, scientific speculation would be too wild and unintegrated. Thus it is a warning that too many steps in the development of science cannot be skipped. This is not a matter of time since development can be slow or rapid; but it must always integrate itself with what has gone before. With this principle in mind, science is justified in holding in abeyance, or in throwing out, all theories which, though they check with sensory fact, make no connection with the given stage of knowledge. We are reminded of the anecdote of the Pope who rebuked Galileo by saying that the earth could move around the sun or the sun around the earth. Here was an anticipation of relativity

which could have no scientific standing since it was highly disconnected from the stage of scientific inquiry of that day. Again, the alchemists' theory of the transmutation of the elements has been shown to be possible; nevertheless, alchemy has no scientific standing, since it failed to show how the transmutation was to take place.

The occult sciences of our day—astrology, theosophy, and spiritualism—may entertain theories which are true, and certainly they have unearthed facts for which some accounting will have to be made, but they are rejected by the body of science to-day for the simple reason that so far they have not been confirmed by scientific theory, i.e. no explanation in terms of accepted scientific facts has as yet been given. Thus in spite of their sensory data, which is empirical, these sciences are not empirical. All this is another way of saying that sensory facts by themselves are not enough for scientific empiricism but must be supported by theory which economically embraces all of them and shows them consistent with older accepted theories.

RELATIVITY OF EMPIRICISM

Empiricism is a relative term. It is relative to the prevailing acceptance of what is real. This broad statement must not be read to mean that what can be considered empirical is an arbitrary affair. It is, on the contrary, a fixed affair, as we have shown, always inevitably dependent upon the stage of knowledge at any time. But no more is it a matter of the subjective will. Neither the impulse nor the reasoning of the individual can make empirical what is not empirical, nor make what is non-

empirical empirical. To explain what is meant by saying that empiricism is a relative term, we may give three examples of its relativity.

First, what is empirical for one science is not necessarily empirical for another. The atom of physics is an empirical entity—for physics. The atom of chemistry is an empirical entity—for chemistry. But the atom of chemistry, with its many combining qualities, is not empirical to the science of physics, the only empirical property for the latter science being its mass. In biochemistry the biological functions of growth, self-repair, and reproduction are not empirical; whereas in botany and animal biology these qualities are the most empirical. For the etiology of disease, capitalism is not an empirical fact, whereas for political economy it most certainly is. In other words, for any special science the empirical can only apply to what is relevant. And the relativity of empiricism is seen to mean the relevance. It does not necessarily follow, however, that all these examples are reversible. On the contrary, as we shall show,[3] the series of relevance is non-reversible.

Secondly, what is empirical for any science is not necessarily empirical for common sense. This should be obvious. The symbiosis of biology, the dipole orientation of electromagnetics, the spinors of mathematical physics, the joint cost of economics, the pyritohedrals of crystallography, are none of them observable to common sense, that is to say, they are not empirical to common sense, but require special knowledge to be observed.

Thirdly, what was once non-empirical can become

[3] *Cf.* p. 148.

empirical and *vice versa.* The former assertion will be readily acceptable. We have only to mention electrons, protons, quanta, vitamins, planets, etc. The latter assertion is not so readily acceptable, but true nevertheless. Phlogiston, caloric, epicycles, the bodily humours, these were once empirical entities, empirical by every test that science could devise. They were manifest in sense experience and they agreed with the existing body of knowledge. But these entities which were empirical are no longer empirical because they no longer answer the second requisite, i.e. they no longer agree with the accepted systems of knowledge, or at best they are not necessary and therefore they are thrown out on economical grounds. For instance, forces are not required to explain anything; they are therefore dropped. Entities which are found to have no necessity are destroyed rather than allowed to multiply, in the interest of empiricism.

Three kinds of entities appear in science, the empirical: the heuristic, and the mythologic. An empirical entity is any entity whether actual or non-actual which has been tested against actuality and found to be allowed. An heuristic entity is one which is set up but which has neither been accepted nor rejected. A mythologic entity is a purposive entity employed as efficiently causative.[4]

It is clear from the foregoing that empiricism is a constant function which has to do with self-consistency within a given system, granted the understanding that any such system indirectly and finally rests on undeniable brute facts. Into and out of this constant function,

[4] No derogation of the reality of purposive entities is intended, but only of their illicit use in science.

items pass, so that while the empirical colours are fading on some entities, others are being freshly painted with them. But the fact that entities once deemed empirical are no longer so considered means only that such entities have been redefined and given new terms; and that new entities constantly enter the empirical field means simply that knowledge of the world is increasing with the progress of science. Too much has been said about the 'fictions of science.' In truth there are no fictions in science in so far as there is science. The fictional aspect of scientific entities, such as forces, phlogiston, etc., is the illegitimate attribution of actuality to the name of a function. When the names of these functions are changed, the fiction of the old disappears, but the truth about the function remains. Scientifically, the 'fiction' never was a fiction.

There are, then, no limits to what may become empirical. What may become empirical is limited only by its ability to continue to have relations with existing knowledge in an orderly, economic, and necessary manner. In short, there are no limits to what can become empirical, but there are absolute limits to empiricism. It must be noted that the degree of abstractness of an entity has nothing whatever to do with whether it is empirical or not.

ALL SCIENCES EXPERIMENTAL

Every science has its empirical aspect. There are no non-empirical sciences. But the experimental field of each science is different, depending upon the portion of the totality of existence selected for study. Every science, in

other words, abstracts from a portion of actuality and omits everything else as irrelevant. The portion of actuality abstracted by physics is not that abstracted by sociology, and *vice versa*. Thus the sciences can be arranged in a hierarchy, according to the level of actuality from which they take their start. This is the hierarchy of the sciences arranged according to their organization of actuality.

Taking our start from physics as the lowest known science in the organization series, we can readily see that the biological is an organization of the physical, and that the sociological is an organization of the biological, and that each of these sciences has, appropriate for study, functions of organization not included in lower sciences. But the abstractiveness of each science is independent of the hierarchy of organization. Each proceeds from brute facts through partly logical actuality to logical abstractions and then on to still more abstractive levels, and finally to still higher abstractive levels where mathematical formulation is possible. It is, of course, true that at earlier stages of abstraction, mathematical formulation is possible; but if a science becomes mathematical before it is sufficiently abstractive (i.e. before it is sufficiently logical) its mathematical formulations will have little validity.

No matter how abstractive a science becomes, it is not carried to the next organizational level. The abstractive level goes out, not up; and the organizational level goes up, not out. Quantum mechanics does not help in the understanding of heredity, any more than did Newtonian mechanics. The appropriate field for experimental

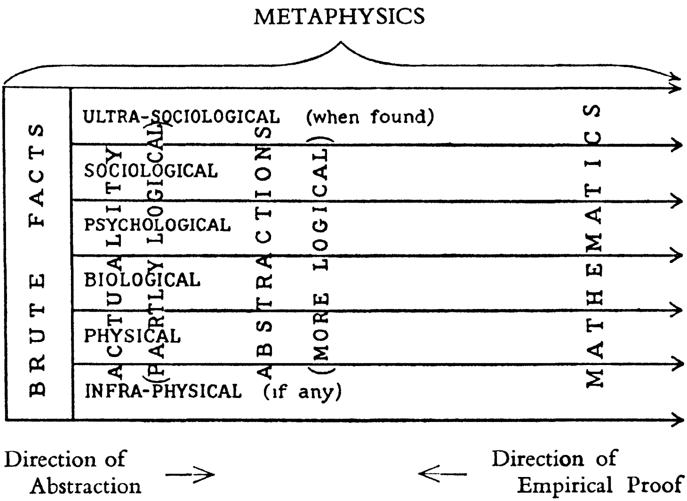

DIAGRAM I

THE FIELD OF THE SCIENCES

The diagram is not intended to be an exhaustive list of the sciences. We have given the main divisions which, broadly speaking, may be taken as including the others. For instance, physics includes mechanics, thermodynamics, chemistry, crystallography, astronomy, physiology, medical science, etc.; sociology includes economics, anthropology, politics, philology, criminology, etc., and each in turn may have its subdivisions, *ad seriatim*. We have included, however, at separate levels the infra-physical, if there be any science dealing with organization at a lower level than the physical, and ultra-sociological, when that science is discovered.

demonstration is the total ground covered between brute facts and the point arrived at in abstraction. The empirical proof works back to the less abstract, and not up in the organizational series. We cannot demonstrate the validity of bimetallism by reference to the atomic table of the elements. We cannot disprove the teleology of living organisms by reference to biochemistry. We cannot demonstrate free will at the sociological level by reference to indeterminacy at the sub-atomic level.

When we state that the appropriate field for experimental demonstration is the total ground covered between brute facts and the point arrived at in abstraction, we mean exactly what was stated above,[5] where it was said that the first empirical test in science is that of self-consistency within the given system, that self-consistency within the given system is *ipso facto* dependent upon sensory (i.e. brute facts) but involves something more. In the empirical proof it is always possible to return to the level of sensory brute facts, but it is seldom necessary. Empirical proof usually consists of going backward one step to the immediately preceding stage of abstraction. The new and more abstract generalization is empirically proved when the immediately preceding abstract generalizations are shown to be more special instances of the one under consideration. This holds for every branch of science; and to the extent to which every study generalizes *in this way* it is equally empirical.

[5] See this chapter, section on "The Principle of Economy."

THE EXPERIMENTAL SCIENCES OF LOGIC, MATHEMATICS, METAPHYSICS

The classical sciences, e.g. physics, biology, etc., are recognized to be empirical sciences. But logic, mathematics, and metaphysics are not so recognized, chiefly perhaps because they do not fit into the hierarchy of sciences arranged according to levels of actuality. As our diagram suggests, logic and mathematics can be abstracted from any and all sciences or from brute facts directly, whereas metaphysics is the widest generalization from all knowledge, including logic and mathematics as well as brute facts and the sciences. But, as we have shown, the empirical status of science has nothing to do with the organizational series. The series only delimits what are the empirical fields for those sciences. We shall show that logic, mathematics, and metaphysics themselves can be and indeed must be empirical.

Logic is an empirical science. When abstracted and presented as an independent system, logic is independent of actuality. But it rests on the most empirical facts in experience, namely, the distinctions and differences between brute facts, without which there would be no such facts. The three postulates of Aristotle: identity, non-contradiction, and the excluded middle, are the basis on which all logic rests. But they themselves are not susceptible of logical proof; they are indeed the basis of our sensory knowledge of brute facts. Thus they are empirical in the most radical sense. Our experience starts with the separation of a brute fact from its surroundings, and the recognition of it (*a*) as an

identical fact, (*b*) as being not its environment, and (*c*) as having no zone common to it and its environment.

All the formulations of logic, then, start with the brute fact of identity, without which nothing would be experienced. But once abstracting identity and its implications, logic treats the purely formal and abstract system so derived as itself a series of given facts, and proceeds to draw further inferences from them. Thus the major and minor premises of every syllogism are brute givens, corresponding to the accepted theories of the physical sciences, which in turn rest on brute difference, just as the theories of science eventually rest on brute sensory fact. The ideal science of logic corresponds exactly to those sciences which have abstracted from actuality. All the propositions of logic are stated conditionally: if *A* then *B*, just as all the abstractive laws of a science are so stated, e.g. if action then reaction. Thus both logic and natural science are free from actuality in their formulations but applicable to actuality conditionally.

If logic is an empirical science, then so is mathematics. Mathematics is merely one kind of abstract extension of logic, rigidly depending upon the laws of logic, and thus finally resting upon basic difference. A large part of mathematics, however, depends upon assigning exact measurements to difference. Mathematicians try to arrive at the most general and abstract formulation of what appears experimentally as special mathematical formulation. The instantaneous speed of a moving object and the tangent of a curve are both generalized under the same formula, $\frac{dy}{dx}$, where y is indifferently the distance

or the ordinate, and *x* indifferently the time or the abscissa. The fact that the generalization covers the special cases can only be proved experimentally. Thus all operations in mathematics are experimental, even when they do not appear so. But in certain instances the method is more obviously experimental. The method of finding invariance under successive transformations in affine and projective geometry, and in the theory of groups, is that of performing operation after operation to find empirically what properties of the system remain identical.[6] Thus the theory of invariance is arrived at experimentally. To quote Felix Klein, the problem is

> Given a manifold and a group of transformations of the same, to develop a theory of invariants relating to that group.[7]

The fact that the operations of mathematics are so far removed from sense experience does not make mathematics one whit less empirical than chemistry.

The statement that metaphysics is also properly an empirical science is apparently hard to accept. In fact the quarrel with metaphysics is just that it deals with absolutes which are beyond demonstration. But when we take into consideration that metaphysics is a certain kind of

[6] But this is only what is done in every science: the accidental is discarded and the necessary retained. However, what is accidental for one department of science may be necessary for another. Black spots before the eyes are accidental for bacteriological analysis but necessary for medical diagnosis. Similarly, what is not invariant (i.e. changing) under a group of transformations also may be studied for change as itself an invariant.

[7] Cited by E. T. Bell, *The Queen of the Sciences*, p. 69.

generalization and abstraction from actuality and brute fact, we shall more clearly see what its experimental field is. It is obvious that a metaphysical system which fails to check with the accepted theories of science and the facts of common experience is a bad one, and will never gain any lasting acceptance. The task of philosophy is made difficult by the very fact that its generalizations must embrace so much, and thus its conclusions are more tentative than those of the special sciences, since metaphysics must stand the test of all knowledge. But this fact does not mean that it is thereby rendered exempt from its proper empirical test. Agreement in philosophy is thus far a great deal harder to attain than in science. But random vagaries and vague mysticism are no more philosophical for philosophy than they would be scientific for science. Moreover, every metaphysical system must be self-consistent, since this is everywhere the empirical test. And like science, new generalizations which are found to agree with the old are not summaries merely but throw light on new facts. Thus ontology, like the self-consistent systems of science, is a fact-finding instrument and not simply a systematic accounting and arrangement.

To generalize from our investigation of empiricism in the various fields, the essential nature of empiricism is the limiting conditions of the speculative reason. Thus what appears as speculative from the immediately preceding lower level of abstraction appears as empirical from the immediately following higher level. What is involved is a matter of direction and not one of intrinsic

dissimilarity. The distinction between the empirical and the logical has been too severely drawn. All that empiricism states is that nothing can be constructed except in and through lower levels of accepted fact, which, abstractive as they may be, finally rest upon the mere faith in the bruteness of given sensory experience. From the brute given upward indefinitely, all that matters is self-consistency and economy. Empiricism finally reduces to the question of relevance.

CHAPTER VII

THE LOGIC OF SCIENCE

Nature syllogizes from one grand major premiss. . . .

CHARLES S. PEIRCE

INDUCTION AND DEDUCTION AS DIRECTIONS

The close relationship between empiricism and logic has been indicated. It must now be further explored. To do so we must first examine inductive and deductive logic, and then show what these mean in terms of scientific method. Some scientists make the mistake of supposing that scientific method is exclusively a matter of induction, whereas others suppose, just as mistakenly, that scientific method is exclusively a matter of deduction. A plague should be cried on both these houses. Scientific method requires both, and the validity of the one certainly requires no rejection of the other. The two methods are complementary and not antithetical. From the point of view of logical experiment, deduction is the process of drawing necessary conclusions from premises. Induction is the choosing of premises.

What is induction? It is a process which starts with certain givens and moves to a generalization which will subsume them so that they appear as related parts of one system. The movement of induction is always in the direction of greater generality, from the less general to the more general. Irrespective of what mental aspect an induction is, it appears logically as a partial sublation of

otherwise unsublated data, and therefore as an explanation, since the explanation of anything consists in its being assigned a place in a system.

What is deduction? It is a process which starts with a given generalization or system and moves to find the parts of that system included as implications. The movement of deduction is always in the direction of lesser generality, from the more general to the less general. The explication of any system is all the deductions which can be drawn from it.

We can see that the possibility of induction or deduction takes for granted the existence of both. Without data no induction could be made to a system; without a system no deduction could be made to implications. The movement in the first case is up from the parts to the whole; the movement in the second case is down from the whole to the parts. The main and important distinction, logically speaking, between induction and deduction is one of direction.

We are trying to present a system of relations which is discovered by two methods: induction and deduction. The start can be made from any given system, and that system analysed into subsidiary systems, or synthesized with other systems into a more inclusive system. There are thus series or layers of systems, arranged in a hierarchy by order of inclusiveness, which the mind ranges over by running up inductively or running down deductively. Inductions always have a deductive background, whether this is recognized or not.[1] And what is induced to is

[1] "Practical inventions do not really come as 'bolts from the blue' to those who have never thought of or studied a given topic. . . .

always another deductive level, whether this is recognized or not.

The relevance, then, of any item to any other item can only be by reference to place within a system, and cannot refer to anything outside that system. This makes possible the investigation of a system in isolation, otherwise impossible. If everything in the universe had to be taken into account in order to explain an item, explanation would be impossible. But explanation is made possible by confining attention to a given system. This fact defines relevance and irrelevance. We have already demonstrated relevance. Irrelevance consists in referring to something outside a given system as an explanation of something inside the system. For instance, the analysis of a dining-room table into legs, top, drawers, etc., does not involve the system of which the dining-room table is a part, e.g. other furniture in the room, or the room, or the economy of the household, etc. Therefore to bring in these wider systems in the analysis of the table is irrelevant. On the other hand, synthesis is impossible merely in terms of elements of analysis, since no number of items of a system can by themselves yield the whole system. For instance, the freedom of the will cannot be

Even the celebrated case of James Watt inventing the steam engine after observing his mother's teakettle, breaks down when one discovers that other steam engines were already in use and that Watt studied the problem for years before he invented anything. One of the most spectacular strokes of genius in the nineteenth century, Hamilton's discovery of quarternions (which, as he has told us, came to him in a few seconds), is known to have been based upon twenty years of study of the very problem which he suddenly solved" (Gardner Murphy, *A Briefer General Psychology*, p. 358).

inferred from the Principle of Indeterminacy at the sub-atomic level. Nor can biological phenomena be entirely explained in physico-chemical terms.

Induction and deduction constitute the movements of logic. But logic *per se* has nothing to do with anything moving. It deals with the conditions of possibility. Actuality we take to be the succession of sensory facts which can be experienced. The logical order of possibility is not a temporal succession at all, but a set of unchanging conditions mutually implicative. All logical propositions are thus formal and have nothing to say about any actual thing or event. To apply logic, therefore, in natural science, other factors than the purely logical must be considered, since science is concerned with determining the extent to which actuality is formal.

THE LOGIC OF SCIENTIFIC METHOD

Since science is concerned with actuality to the extent to which it is formal, scientific method must be a particular application of logic.[2] The very feasibility of the application of formal logic to actuality in scientific method presupposes the continuity, or what John Stuart Mill called the uniformity of nature. It takes for granted that nature is objectively a consistent system, continuous and uni-

[2] Since experimentation seems to deal with sensible qualities, and logic with formal qualities, the conception of the logic of science often appears to the experimenter to be a contradiction. But in successive experiments the sensible qualities change, whereas the formal qualities remain the same, and it is the latter which enable an experiment to be called scientific. The presence of the sensible qualities blind the experimenter to the fact that from his point of view the formal are prior.

form, which can be known. We have shown that logic deals only with possibility and not with actuality, and that scientific method deals with the verifiable possibilities of actuality. For instance, that all unicorns are horses having a single horn, is a proposition which has no application to zoology since no actual unicorns have ever been observed. In other words, both the major and the minor premises of a logical proposition are always ideal and conditional, i.e. possible.

> *If* unicorns are horses having single horns,
> And *if* this horse has a single horn,
> *Then* this horse is a unicorn.

But scientific method differs from formal logic in having as the minor premise an actual fact, i.e. in determining that the condition applies. And this is what experiment or demonstration is.

> *If* unicorns are horses having single horns,
> And *since* this horse is observed to have no horn,
> This horse is not a unicorn.

The first syllogism is purely logical; the second corresponds to the procedure of scientific experiment. It must be noted that in both syllogisms the major premise is conditional and ideal. As far as deduction is concerned, the major premise is treated as given, and has empirical standing, having itself once been the minor premise of some other syllogistic movement. In science, inductions from observed facts, when mathematically formulable, have been employed to yield new results deductively. But the inductions from which this train of reasoning

started have often themselves later been shown to be deductions from some apparently unrelated deduction. For instance, Balmer's Law for the position of lines in the hydrogen spectrum was a mathematical induction from certain observed measurements. Since this time the law has been deduced from wider systems: atomic theory and quantum mechanics, which have been shown to include Balmer's Law as a special case.[3]

Scientific method, in contradistinction to logic, involves two procedures: it goes down to be tested against actuality; it goes out to be tested against a given system for logical consistency. Thus again it is the logic of actuality. On p. 132 above we showed that Einstein's general theory of relativity was demonstrated in two ways: by testing against actuality in the three experiments noted; and by logical consistency, showing that it agreed with the previous body of physical knowledge. The test by actuality or experimental demonstration is not a proof of the validity of the scientific hypothesis involved; it is merely an allowance; whereas the failure of the empirical allowance of an hypothesis does constitute an absolute disproof.[4] It should be noted that the appeal to prediction is one form of the appeal to actuality. The test by consistency with logical possibility is proof. For proof means the ability

[3] We owe this illustration to Morris R. Cohen, *Reason and Nature*, p. 120 f.

[4] On page 150 we gave an example of the syllogism of disproof. We may also give here an example of the syllogism of allowance.

> Perhaps all frogs hop,
> Certainly some (all observed) frogs hop,
> Therefore it has not been disproved that all frogs hop.

to place a given item in a system where it will form part of a larger system without disturbing its consistency. Thus empirical proof is allowance; logical proof is proof.[5] Chantecler's theory that he crowed up the sun was not proved by the many times that the coincidence happened, but was absolutely disproved by the one time that it didn't. As Jeffreys says,[6] "one of the chief functions of exceptions is to *improve* the rule."

The two procedures can be validly conducted without reference to actuality—solely on the level of possibility. This is what happens in the science of mathematics, where the proof of logical consistency and the test by experimental demonstration turn out to be identical. The only possible tests in mathematics are to verify the consistency of a given mathematical hypothesis by reference to sub-systems, or to wider systems. That is what experiment means in mathematics.[7]

But the two procedures cannot be validly conducted solely on the level of actuality and without reference to possibility. Here the two movements are not the same. For to transport the two procedures to actuality means that the major premise of the syllogism which corresponds to experimental demonstration must also be an actual. When this is done, the procedure down to experimental demonstration is retained, but its logical consistency is omitted, and what results are so-called

[5] *Cf.* the instance of Balmer's Law, p. 151, where induction is eventually shown to be a special case of deduction from a more inclusive induction.

[6] Harold Jeffreys, *Scientific Inference*, p. 5.

[7] For a good illustration of this, see H. Levy, *The Universe of Science*, p. 116 f.

empirical laws, generalizations from observed phenomena which may or may not hold as laws.

> England was prosperous under Elizabeth, Anne, and Victoria,
> England is always prosperous under queens,
> Therefore England will be prosperous under the next queen.

Or, formulated deductively,

> Prosperity under Elizabeth, Anne, and Victoria means prosperity under all queens,
> Queen X is a future queen of England,
> Therefore England will be prosperous under Queen X.

This is an empirical law which, like all other empirical laws, holds only with exceptions. It is therefore not a scientific law. The next queen may disprove it. The difficulty lies in the lack of logical consistency, there having been no necessity shown between the sex of the monarch and the prosperity of the realm. If such necessity could be shown, it would take the form of a logical proposition and not of an actual fact. *No* exception can prove a rule; but on the contrary *any* exception can disprove it.

It is therefore true that all scientific laws must occupy the status of ideality, of possibility, and cannot be mere generalizations of actual facts.

Experiment is a variety of deductive logic, that variety where the determination of implications involves reference to the observation of actuality. But logical analysis equally involves experiment, though here the experi-

ments performed do not candidly present themselves as such. For instance, the analysis of the term 'queens' or the term 'prosperity' cannot be made without reference to a typical case. Such reference constitutes a logical operation. Experiment is involved in logical analysis, and logical analysis is involved in experiment. The proof by deduction and the proof by experiment turn out to be the exploration of what is involved in a system (i.e. its implications) so that all the parts of the system are seen as consistent parts of a larger system.

Those who say that analysis or deduction is the whole of scientific method have been misled by too narrowly considering scientific procedure, which always analyses to establish an hypothesis. They have neglected to perceive that no analysis can be effected except in terms of an embracing system, and that such systems are not merely given to ordinary observation, but require insight and valid induction.

ANALYSIS AND SYNTHESIS

We have shown the two movements of logic in scientific method and the absurdity of trying to confine scientific method to either movement. The difference between induction and deduction is a difference of direction, so that what is an induction from one level is a deduction from a higher. The same thing applies *mutatis mutandis* to the question of reason and empiricism, where reason alone or empiricism alone is championed to the exclusion of the other. It has been shown that any theory arrived at by speculation may become an empirical fact, and is *ipso facto* an empirical fact when deduced from a higher

level. Thus what is speculative from one level is empirical from another, and again what is involved is a matter of direction. The further problem of the difference between pure and applied sciences is resolved in the same manner, by showing that there is no absolute distinction but only a relative one.

The exclusive reliance on rationalism or empiricism produces a pair of dogmatisms. Rational dogmatism consists in the assumption that it is possible to reason to the facts without the aid of experimental demonstration. Plato's dogmatic rationalization that the universe being harmonious, there must be harmonic intervals between the planets, was overthrown by the empirical observations of Tycho Brahe. The mistake lay in supposing not that there was a regularity, but that the particular regularity could be found by deducing from the larger system. Empirical dogmatism, on the other hand, consists in the assumption that it is possible to discover laws without the help of the speculative reason. The social scientists working from this position have been accumulating experimentally determined facts for decades, without having been able to produce a single valid law (from the very fear of being too speculative).

Rational dogmatism and empirical dogmatism are each half-truths and half-errors. The truth of rational dogmatism consists in the fact that reason is required as pointing the way down towards discovery, without which there could be no discovery. The truth of empirical dogmatism consists in the fact that without experiment the nature of the constituents of a system can never be known (no number of theories being able to prove an

actual). The error in rational dogmatism consists in the truth of empirical dogmatism, and *vice versa.* Rational dogmatism is uncontrolled speculative generalization; empirical dogmatism is positivism. One never touches the ground; the other never leaves it. Scientific method cannot be confined to either but must employ the truth that is involved in both, in a complementary manner. Where empiricism and speculation are seen as two directions, it becomes clear what the limits of each are. Since the explanation of anything lies in showing its consistency within a larger system, speculation about that larger system is the first requisite. But the placing of the parts of the smaller system within that smaller system is irrelevant to the larger system. And thus the second cannot be deduced from the first.

Equally, it is impossible to find a system which explains the parts of analysis of the parts, since this is looking in a lower system for an explanation of the higher. The attempt to jump from the constituents of one system to another system either higher or lower is misleading and fallacious.

We now come to the relative distinction between pure and applied science. Sciences cannot be divided into those which are pure and those which are applied. Some sciences appear to be merely applied sciences; their theories are not in evidence because they are overlooked or have not been formulated. Agriculture is an example. Other sciences appear to be pure or merely formal because little or no application has been found for them. For example, many branches of mathematics have remained notoriously pure, i.e. no use has as yet been found for

them. But scientific progress has moved two ways: toward the abstract formulation of applied techniques, and toward the application of pure formulations. The practice of medicine which was altogether and is still somewhat an εμπειρία is daily becoming more of a τέχνη, as is also cookery, business management, etc. On the other hand, conic sections, non-commutative algebra, and the tensor calculus were once branches of purely formal science, for which applications were later found.

Within any given science, every abstractive level appears as formal to the level below it, and as applied to the level above. Physics appears as 'formal' to technology, and mathematics appears as 'formal' to physics. Conversely, technology appears as 'application' to physics, and physics appears as 'application' to mathematics. Thus so apparently useful a discipline as technology is a formal study from the point of view of its application to industry. And so apparently abstract a study as higher mathematics is an applied affair from the point of view of logic.

We have in this section been exhibiting a single point which appears under several guises, namely, that there are levels of investigation which require two directions to be fully understood. Only one direction can be employed at a time, but both must finally be employed in each instance of scientific method. We have seen this point illustrated in the question of induction and deduction, rationalism and empiricism, pure and applied science. But in science, this quasi-opposition is more familiarly known as the problem of mechanism versus teleology or purpose.

MECHANISM AND PURPOSE

Mechanism and purpose in science are merely the general doctrines covering the questions of analysis and synthesis, the employment of empiricism, and the speculative reason. Mechanism in science states that the explanation of the phenomena of nature requires only an analysis of given items into constituent parts, and that such an explanation exhausts the phenomena without the introduction of purpose. Purpose, it further states, is an unnecessary and thus an illicit conception, and efficient causation is alone scientific. Those who oppose this doctrine maintain that many of the phenomena of nature cannot be explained without introducing the category of purpose, and final causation. Purpose in science is the statement that any given item contains more than the sum of its parts.

Mechanism is known as atomism, materialism, "physicalism," etc. Atomism is the variant which may be defined as the belief that all things are the results of unchanging particles in motion; materialism, that matter alone is real, and all else configurations of it; and physicalism, that all the sciences are reducible to the science of physics. Purpose is known as vitalism, creative evolution, entelechy, etc. Vitalism is the variant which may be defined as the belief that a mysterious binding quality, called life, is involved in living organisms beside their material parts; creative evolution, that there is a force, e.g. the *élan vital*, which is the 'drive' working within things toward some mysterious end; and entelechy, that there is a mysterious determining principle germinating within things to guide them toward an end.

Both these doctrines fail to be completely explanatory of scientific method or of the data with which the sciences deal. Mechanism accounts for analysis well enough, but fails to account for wholes which defeat every effort to build them up with elements of analysis alone. Purpose accounts for organizations well enough, but begs the question of constituent parts which cannot be accounted for by purpose. It is quite understandable why most scientists should consider that purpose is not properly part of the procedure of science, since it does not appear under this guise. Purpose appears in scientific analysis not as purpose but as empirical fact, and it is only recognizable as purpose in regard to systems above it. For instance, in the analysis of blood, blood appears as an empirical fact, a brute item for analysis, and it is only with reference to the function of blood that one can recognize this empirical fact to be also a purposive affair in regard to the nourishment of tissues, etc. In isolating an item for analysis, it is forgotten that the only canon of isolation in the first place was its purpose. Function is purpose, and function defines an item.

The inception of any single application of scientific method presupposes an hypothesis or an induction (purpose) at once predicated and left behind. The scientist is mainly concerned with exploring the deductive implications of an hypothesis, and thus he tends to forget the original leap to the predicated purpose. It is not easy to see a scientist leap to an hypothesis in the bathtub, but anyone can actually observe him working in the laboratory exploring deductive implications. The fact that mechanism is indefinable without purpose is well shown

when we consider the definition of a machine. A machine is a purposive organization of parts and not a mere agglomeration.

On the other hand, the presence of purpose in scientific method does not mean that the vitalistic theories are valid. Purpose is not a mysterious something added to empirical entities to give them 'meaning.' It is the relation which the parts bear to a whole. Necessarily such organization is abandoned in analysis. But this does not mean that it does not continue to exist. Water is not composed of oxygen, hydrogen, and wetness, but of oxygen and hydrogen in certain proportion and organization, which is water and, as such, wet. Since purpose is, then, the organization of parts, it is not to be found in the parts alone; it is the whole of a system and not any part. Thus the attempt to find a life principle, an entelechy, etc., in analysis is an absurdity.

Both mechanism and vitalism are each partly true, though each in itself is false if taken as being the whole truth involved. Both mechanism and vitalism, as false, point the same moral as the exclusive claim of analysis and synthesis, namely, that of trying to account for the whole of scientific method by one direction instead of by two. Mechanism and purpose yield the same caution: it is impossible to move from the parts of one system outside that system. Mechanism as an exclusive theory wrongly supposes that the sub-systems of parts can yield the system which includes those parts. Purpose as an exclusive theory wrongly supposes that a system which embraces given systems as parts can be brought in to explain the parts of the embraced systems. An example of

the first error is the proposition that life is a property of the carbon atom. An example of the second error is the proposition that the *élan vital* works on the carbon atom to produce living tissue.

In conclusion it should be pointed out that mechanism *as a method* in science is the essential element, since every purpose is explained only in terms of elements of analysis in relation to a system, i.e. for science purpose is the explication of the *how*. But the positivistic reading of mechanism as a scientific *philosophy* would exclude purpose, and therefore if followed logically, exclude also induction and hypothesis. It would thereby prevent all advance. Mechanism is just as vicious as purpose when erected into a scientific philosophy. In science what appears as purpose is rightly considered in its empirical aspects, i.e. analysed down, and when so analysed kept clear of higher systems. This is the empirical method.

DEDUCTION VERSUS IMAGINATION

With the understanding that deduction alone is insufficient in science, and that purpose is implicitly involved in the start of analysis, we shall attempt to show that the direction of the development of science involves a greater and greater use of deduction and a lesser reference to purposive entities.

With the development of a given science inductively the consistent logical system becomes by definition wider. This means that higher levels of abstraction are being attained, and that the appeal to actuality for allowance or disproof becomes less and less necessary. When a

science is in this advanced stage of development, it has resort largely to mathematical formulation; its deductions yield brilliant results, often more brilliant than those attained through induction. Induction is not abandoned when a science advances to the mathematical stage, but it becomes less apparent, and requires less imaginative flight, approaching closer and closer to the process of deduction.

We have shown that in mathematics the empirical proof can be either deductive or inductive, and that both are experimental. The place of brilliant insight in the advance of science has perhaps been over-emphasized, particularly in the more developed sciences. Brilliant results do not necessarily mean brilliant insight. Emile Meyerson points out that many of the discoveries which have been arrived at by deduction could never have been the results of imaginative insight, since they are too fantastic ever to have appealed to any scientist. The superhuman vision obtainable with the photo-electric cell, is the application of a deduction from sub-atomic physics, and is certainly one which could never have been imagined. The same is true of television. None of these is as remarkable a feat of scientific imagination as the public assumes. They are clever adaptations of deductions from known principles.

Admitting, however, that great scientific discoveries have been made inductively, through psychological insight, does not logic play a large part here as well? Are not scientific discoveries as much a function of the given stage of a science's development as of the imaginative capacity of the individual scientists? Certainly successful

scientific 'leaps in the dark' are not made by those ignorant of the background of the scientific system. They are not made by poets and prophets but often by scientists otherwise prosaic and unimaginative. Scientists who make brilliant guesses do so because of their knowledge of the consistent system which presents itself as a series of deductions. The logical status of a science is important in the understanding of scientific discovery and advance. The rapid advance of physics as contrasted with social science is certainly not to be explained by supposing that all the genuises have become physicists and that social science has in its service only mediocre intelligences.

The development of a science to the level of abstraction which is fit for mathematical formulation accomplishes something else of value. It reduces to a minimum mythologic entities, which are the cryptic introduction of purpose into scientific analysis. For instance, medical science which has not reached the stage of physics or chemistry is cluttered up with such mythologic and crypto-purposive entities as immunity, resistance, defence, antibody, agglutinin, lysin, etc. The scientific problem concerns the analysis of these entities into their mechanisms. They are useful, but only in the intermediate stages of science. In a mathematical-deductive science, like physics, purpose appears as the geometric properties of an arithmetic system.

Thus induction and purpose do not disappear in the development of a science, but begin to become one with deduction and mechanism. In the ideal science all principles appear arranged *ad seriatim* as deductions from a single grand major premise. And purpose is seen as the

hierarchy of the organizational series of systems in one system.

HOW SCIENCE SHOULD PROGRESS

We have been presenting the logic of science as direction of movement in scientific discovery. Induction, synthesis, purpose, hypothesis, are all indicated as the directions up toward the more embracing, or that which embraces. Deduction, analysis, mechanism, empirical proof, are all indicated as the direction down toward the less embracing, or that which is embraced. These movements of discovery imply an order of existence to be discovered. This order of existence considered by itself cannot properly be called a direction or movement, since it does not change. It is a completely independent system, a hierarchy of embracing and more embracing functions, which are therefore independent of any method of discovery. It will be recognized that this must be the case, since we have shown that what is an induction from a given set of data is a deduction from another seemingly unrelated induction. Thus induction and deduction are seen as different approaches to the discovery of the same set of conditions.

This independent set of conditions or, as we have previously termed it, this hierarchy of functions, may be compared with a spider web, in which the concentric threads form a dense manifold. Each thread embraces all threads below it as themselves less embracing. The investigator is the spider, not as the spinner of the web but as the one who can move over it, but only in one direction at a time. Obviously, when the spider is in a

shorter orbit, all outer orbits are to the spider more embracing or 'up' in the series; but when the spider moves to an outside orbit the shorter orbits are less embracing or 'down' in the series; yet they remain unchanged by the spider's position. The logical order of existence is independent of the method of its discovery. But obviously the method of discovery must conform to the logic of that which is to be discovered.

In the conception of scientific method which we have been setting forth, given a dense hierarchy of functions, empiricism is the proof by logical consistency downward, a checking over of included systems to show that the more inclusive system from which the investigation starts is logically a system of those systems. We have further shown that whether this proof takes the form of experimentation candidly, or of deduction abstractly, the method is the same, requiring both logical consistency and experimental verification. In some cases these are identical.

The way that science has progressed is not the ideal of science. The ideal method which should obtain and which begins to obtain whenever a science approaches a certain stage of development, is quite something else. When large inclusive systems are reached in a science, every other system must be shown to be a deduction from it, and lesser systems deductions from those, *ad seriatim*, until the whole system is seen as a pattern which interlaces, and thus no item appears as disconnected from the rest. Granting that such an ideal could be approached, the need for allowance or disproof by reference to actuality must become less and less requisite, and proof

by logical consistency serve the task of both proofs. The more that is known of a system, the less investigation is required to determine whether a newly discovered item is or is not a part of that system. Just as a nearly completed picture puzzle is easier to complete the more nearly it is completed, because the remaining pieces are readily found to fit, so it is easier to determine where a new piece of knowledge will fit in the scheme of modern mathematical physics. And the reverse is true of the effort to determine the place of any item of knowledge in such an unorganized science as political economy. By the same token, it follows that the imaginative genius required to initiate a science is far greater than that required to help it to progress after it has reached a certain stage.

The ideal science presupposes the completion of the discovery of an already existing system. Obviously, there is as yet no such science, and it is of little practical help in producing one to refer only to what one ought to be when completed. Yet for the perfection of working method it is necessary to know what the ideal is. The ideal *working* method of science is the subjection of every hypothesis, after empirical proof, to subsumption by a more inclusive hypothesis which shows it as a special case of the more inclusive, i.e. as a deduction from it. The movement is, therefore, in widening concentric circles, so that the older and lesser hypotheses are shown to be more restricted than was formerly supposed, but perfectly valid within limits. Thus no scientific theory is ever truly abandoned, as it would seem to those ignorant of scientific method. The advance of science does not stagger

from extreme to extreme, abandoning one direction in favour of another, like the practice of politics, but rather resembles the concentric waves in a pond which widen out after a stone has been dropped. Human ignorance restricts at any given time what the last and most inclusive circle shall be; and it is not until contradictions appear to universal claims that men are led to seek for more inclusive circles which will reconcile it and give it proper limitations. This is the best that any human endeavour can expect to accomplish.

CHAPTER VIII

CAUSALITY AND PROBABILITY

In point of fact statistical laws are dependent upon the assumption of a strict law of causality functioning in each particular case.

MAX PLANCK

EMPIRICISM AND CAUSALITY

More is involved in the logical nature of empiricism than the strict question of induction and deduction. The problem of causality arises. That the idea of causality is involved in empiricism is well shown by the fact that all radical empiricists or philosophical positivists deny that causality is an objective fact of nature. Just as the idea of causality is denied by those who see science as a "compendious representation of the actual," so the understanding of science as a purely abstract domain requires causality.

Throughout this book we have been gradually demonstrating the existence of a logical series of functions, independent of observation and mutually implicative. If the radical empiricists are correct in their contention that causality has no objective status, then such a realm of functions as we predicate is challenged and held to be a merely mental construction which has no necessary correspondence to nature. This would make nature an irregular and irrational affair, and would leave as an insoluble puzzle the question of how it could be investigated by the minds of men. Nevertheless, P. W.

Bridgman for one does not hesitate to make the bold assertion that the universe is just this kind of unintelligible affair. He says,

> The world is not a world of reason, understandable by the intellect of man, but as we penetrate ever deeper, the very law of cause and effect, which we had thought to be a formula to which we could force God Himself to subscribe, ceases to have a meaning.[1]

In refutation of this position, there is little more to add to what has already been said in Chapter III. Let us only repeat that if the world is as irrational as Bridgman predicates, then his predication has no standing as true or false. But even if we accept his argument, then the very universality of irregularity implies a kind of dependability upon regularity. Thus irregularity for the totality of the universe is a contradiction.

Aside from such extreme statements as Bridgman's, however, there is a general tendency on the part of physicists and, by consequence, other scientists, to doubt the existence of causal laws in nature. Eddington, for example, asserts that causal laws are truisms, but that statistical laws are real laws which in high averages have given the appearance of causal laws. This rejection of causality implies a rejection of ideal entities, since causal laws must all be framed in terms of such entities. If causal laws are mere appearances, ideal entities have only a fictional value. Lenzen makes the statement that classical physics deals with ideal entities, like "ideal

[1] P. W. Bridgman, "The New Vision of Science," in *Harper's* for March 1929.

particles, ideal rigid bodies, ideal fluids,"[2] whereas modern physics is purely mathematical. The term 'ideal' has unfortunate connotations; it is supposed to mean subjective, imaginative, unreal. But what it denotes is a set of conditions abstracted or isolated from actuality —and only approximated to in actuality. The mathematical symbols, $\omega, X, \delta, \lambda$, are just as ideal as chemically pure iron, absolute rigidity, etc. An ideal proposition is one to which no actual has been assigned. The whole present misconception that science has abandoned ideal formulations and, as a consequence, causality, rests on the inability to see that mathematical symbols are merely better substitutes for the older ideal entities. We have shown that the nature of such ideal entities was merely mathematical, and that the pictorial representation of them was unnecessary and misleading. But to state that science has taken an entirely new tack because of the elimination of such pictorial representations is evidence of a lack of understanding of science itself.

The idea of causality only *seems* to have been dropped by modern science. There is no categorical distinction between classical physics and modern physics. There has certainly been an advance, but in the direction of greater generality and emphatically not in basically logical procedure. What appeared in classical physics as causality appears in modern physics as function. And it is only because the nature of causality was misunderstood in classical physics, and has since been given a new name, that it seems to have been abandoned. The question of probability versus causality is one of the argumentative

[2] V. F. Lenzen, *The Nature of Physical Theory*, pp. 44–5.

by-products of the misunderstanding of the integral history of science. Its occasion, however, is irrelevant to the logical question of causality, as we shall later show. Causality properly understood by whatever name is implicit in modern as well as in classical physics.

CAUSALITY AND CONTINUITY

Let us leave the subject of causality for a moment and discuss the manifold of natural phenomena as it is assumed everywhere in science. The "uniformity of nature" means a series such that between any two items in the series a third can always be found, and such that in any definition of an item of the series the beginning and end of the item are the end and beginning of adjoining items in the series. Continuity "is the absence of ultimate parts in that which is divisible."[3] It is "nothing but perfect generality of a law of relationship."[4]

In terms of science this means, first, that there are no ultimate constituents of the universe, but that every quasi-element of analysis is subject to further analysis in an unending series, whether such analysis has yet been accomplished or not. Secondly, it means that there is always a system more inclusive than any given system, whether such a system has been found or not. In short, the doctrine denies that nature is discontinuous, and that finitude has any limits. There are no final irrational elements, no brute givens, even though there will always at any time be what appear as brute facts. Such a doctrine is radically insusceptible of proof, yet its ac-

[3] Charles S. Peirce, *Collected Papers*, 6.173.

[4] Ibid., 6.172.

ceptance is tacit in scientific procedure. Thus the molecule was superseded by the atom, and the atom, that supposedly indivisible entity, was superseded by the quasi-ultimate particles, electron, proton, neutron, etc. We take it that science in general will not accept the indivisibility of these entities any more than it did that of the old 'atom.'

Similarly, no system, however inclusive, has persisted as the final system for very long, but one more inclusive has always been found to take its place. Newton's cosmology was supplanted by the relativity cosmology; and we take it as axiomatic that science will not accept as final even the relativity cosmology. Thus science accepts nothing as brute and final except *pro tem.* and of necessity.

The definition of continuity as the perfect generality of a law of relationship means in science that the acceptance of law is equivalent to the rejection of the possibility of exception. As a practical matter, this indicates that what will apply to a given number of instances will apply to all instances, if the abstraction of instances has been fairly made. It indicates also that a given principle remains the same though it appears conditioned in various ways. When Galileo generalized the law of falling bodies, the principle of the inclined plane, and the principle of the pendulum, all into one principle: the law of inertia (to use Newton's later terminology), he was presupposing the continuity of nature. That the assumption was not unfounded, need not be argued. In fact, it may be said that without the assumption of this principle the whole of science would be at best a

description of how certain particular experiments resulted. Science would be a partial history and not a basis for prediction.

What do all these definitions of continuity mean in terms of causality? We have shown that continuity in science means the rejection of anything ultimately unanalysable or ultimate. Science finally refuses to believe that any finite thing is just a brute fact without reason, or that any event is uncaused. To put this in the terminology of cause-and-effect, it means that the minutest elements of analysis at any stage are the result of still more minute elements and, conversely, that the largest system which has been discovered at any stage is the effect of more inclusive systems. Moreover, the acceptance of a principle as operative without exception throughout its sphere of applicability is tantamount to the declaration of inexorability, which is to say, strict causality or causal law. In fact, there is no difference between the acceptance of the principle of continuity or the uniformity of nature, and of strict causality. He who accepts one is perforce driven to the other. The scientists accept causality by accepting the continuity and uniformity of nature. And the fact that they do so implicitly, without awareness of the multiple implications in which they are involved thereby, does not change the situation. Thus every scientist in so far as he is a scientist, and despite his protestations, accepts causality.

CAUSALITY IS NON-TEMPORAL

Why, then, do the scientists suppose that causality has been abandoned in science? The answer is that the idea

of causality has been persistently misunderstood as meaning the determinism of history, a locked sequence of actual happenings. Hume, for instance, denied that there was any continuity, or that there was anything more than a sequence of events which by itself manifests no causal nexus. John Stuart Mill, however, formulated even more succinctly the point of view of the strict mechanistic scientist of the Newtonian era. He defined causality as the aggregate of all the circumstances under which an event occurs.[5] It is this understanding of causality as temporal which modern science has rendered untenable, and which therefore seems to indicate to the scientists that causality has been overthrown.

The most notorious instance of the failure to predict actual occurrences is the behaviour of an actual subatomic particle. But if causality had been properly understood in the days of classical physics, it could have been demonstrated that the inability to predict any actual occurrence with absolute exactitude was due to ignorance of some of the factors involved. When an experiment is performed to demonstrate a law, the attempt is made to isolate a system for analysis. Perfect isolation, however, is never accomplished, because 'controlled conditions' cannot be *absolutely* controlled. Thus every actual experiment will bear out a law only approximately, though often with very minute variations.

The application of general principles to actuality must always admit of modifications, which modifications do not serve to nullify the invariability of the principle but rather serve to modify the actual effects produced

[5] John Stuart Mill, *System of Logic*, book iii, chapter 5.

thereby. Indeed, it is in terms of an unchanging principle that the modifications themselves must be understood. Strict causality cannot be demonstrated because it does not occur pure in demonstration. But this is no proof of its non-existence as pure. Indeed, the fact that its workings can be approximated to in an experiment under properly (i.e. the most perfectly) controlled conditions is an argument for the existence of causality, and not the reverse.

Let us see if 'the aggregate of all the circumstances under which an event occurs' can properly be called causal. Suppose that the chairman of a meeting strikes the desk with his gavel, causing ripples in a glass of water on the desk. The desk had just been painted brown; the weight of the gavel was seven ounces; at the time the event occurred the room was full of people; the initial velocity of the blow was one foot per second; the room temperature was 85 degrees Fahrenheit; the distance from the glass to the place where the gavel struck was sixteen inches; the day was Tuesday in the month of March; the place, Wichita, Kansas. Note that the effect is the rippling of the water in the glass. We have mentioned only a few of the vast aggregate of all the circumstances under which the event occurred. How many of these circumstances bear on the effect as its cause? Causally are they all of equal importance, merely by virtue of their participation in the aggregate? Obviously, the initial velocity of the gavel was of more importance than the temperature of the room. Certain conditions, such as the day of the week, can plainly be ruled out as causes. Without labouring the point, it is

clear that the cause of an event cannot be the aggregate of all the circumstances under which that event occurs, but must be certain of the circumstances.

What, then, is the canon of selection whereby certain circumstances can be called causal and others not? The canon is one of relevance, and the relevance of a *physical* event can only be to a *physical* system. Thus velocity, mass, and temperature may be relevant, but date, location, colour, and social surroundings can have no relevance. But once admitting only physical factors as causal for a physical event, the main cause, of which the others are merely modifying causes, still remains to be isolated. And this can be found only through a general principle known or discovered by experiment. Experimentation in this connection is seen to consist in the reproduction of the event with certain factors omitted and certain kept. When the paring down of circumstances reaches the point where the omission of any more prevents the event from happening, then cause has probably been found. The true cause of the trembling of the water must be laid to the mechanical principle of action and reaction. A cause will always reduce to a matter of abstract function.

Going back to the actual event, can it be said that any factor was the cause of the rippling of the water *before* the event took place? Suppose we take as an hypothetical cause the momentum of the gavel at any time before it struck the table. Then the hypothetical cause was still not absolutely certain, since many chance factors could have intervened to prevent the gavel hitting. The hypothetical cause was only a probability, growing stronger and

stronger as the time interval was cut down. When that time-interval reached zero, the probability of the event happening reached absolute certainty. When event *A* approaches event *B* as a limit, probability reaches certainty as a limit. But when event *A* and event *B* have the intervening time element eliminated, they are not two events but one, *AB*, in which the distinction between *A* and *B* has been made not on a temporal but on a logical basis. Thus cause and effect are seen as a logical nexus and not as a temporal sequence. Causality asserts, *if A then B*. In this particular case, if action, then reaction. This means that two functions are involved in one function, i.e. that two functions have been analysed as parts of a single function.

Here causality shows its true nature as the deduction from premises. Causality rightly understood means that every function is included or is the deductive consequence from a more inclusive function, i.e. is the effect. In other words, it means that the more inclusive function is the cause. When cause and effect are considered in actual happenings, it is the more inclusive function which determines the lesser, and which is segregated as the cause. Causality in actuality exhibits the logical order running through the temporal order. To the extent to which one is able to segregate out the logical element in any situation, that situation will be understood and subjected to control. In a comparatively well-developed science, the employment of mathematics means the widening of the knowledge of the logical order at that level of investigation. Cause and effect appear explicitly as functions. Thus in advanced science, causality seems to be left out. But

what is left out is only the old error of formulating causality as a temporal affair.

PROBABILITY REQUIRES CAUSALITY

The occasion for the apparent abandonment of causality as a principle in modern physics (and *a fortiori* in all other sciences) is the vogue of statistical laws. Modern physicists, assuming that causal laws are coercive, and demonstrating that invariance does not exist in actuality, wish to substitute the idea of probability for that of causality. Causal laws, they inform us, are too rigid, whereas statistical averages merely yield a formulation of what is likely to happen, and thus the concept of probability instead of strict causality reigns.

Can probability be accepted as supplanting causality? In order to answer this question it will be necessary to make an analysis of probability. Abstractly understood, what is it? Probability is the asymptotic approach to certainty. Certainty is the predication of absolute invariance. Probability, then, is that which approaches but never reaches absolute invariance. In the example given above, of the gavel approaching the table, it was shown that as the time-interval decreased to zero, the probability of the gavel striking the table grew greater and greater, until as the time-interval reached zero, probability reached 1, which is the symbol of certainty. Thus certainty cannot be predicted since the time-interval must be zero. Invariance, as we have shown, is a logical affair which applied to any actual occurrence is applied conditionally, i.e. if *A* then *B*. Thus we can speak of the future only in terms of probability, and

this probability increases as the future becomes less remote.

If, then, probability is the asymptotic approach to certainty, certainty is involved in probability. It is predicated as the goal, or else probability would have no definition. Who would attempt to predict the probability of what John Smith is going to think about next Tuesday morning at ten o'clock from the knowledge of what he has thought about on past Tuesdays at ten, unless there were some logical connection between that hour on Tuesdays and John Smith's thoughts? Without the assumption of some logical connection, known or unknown, no one would make a prediction of probability. When the average period of gestation of a human being is said to be 279 days, this means that any baby probably will be born at the end of this period, though there is no absolute certainty and indeed wide variation. Surely such a probability takes for granted that there is some invariant connection between the gestation interval and birth, which is modified by many incidental factors in any given case. The statement that it will probably rain some time next month would make no sense if rainfall were purely a random affair. What gives it meaning is the fact that certain complex factors combine to yield the event wherever undisturbed by still others which are just as causal. Thus causality is always implied in any meaningful predication of probability.

The history of scientific inquiry reveals the fact that causal laws were discovered through the finding of certain behaviouristic patterns where it was probable that certain events could continue to manifest invariance.

Any of the discovered laws of causality might have been formulated by means of probability, i.e. statistically. And so they would have remained, unless science had gone deeper to isolate necessary cause. If, ignoring such questions as air resistance, the law of falling bodies had been formulated statistically, i.e. from a compilation of many actual instances of various kinds of falling bodies, it would have taken this form: it is probable that any object falls at the rate of thirty-two feet per second per second. But instead of this, Galileo made but few experiments—not enough for a law of probability—and leaped to the conclusion that this acceleration was involved in every instance of every falling body, thus showing special cases to be modifications of the principle, because of calculable interfering factors.

The rash overthrow of causality, where laws of probability take their place, is based on the assumption that no causality is involved in probability. This we have shown to be an utterly indefensible assumption wherever statistics are expected to have any relevance to the future. Inasmuch as the laws of probability are relied upon by modern physicists, they are being used as quasi-causal laws, relied upon for their dependability and not for their undependability. They involve causality, whether that causality be known or unknown. And where it is unknown, they are interim laws, which will be discarded as soon as and if causal laws are found. Thus the attempt to predicate statistical laws as final is the same treason to the progress of science as the refusal to admit as possibly existent anything not already demonstrated. Both refusals are involved in the platform of positivism.

THE STATISTICAL METHOD AND CAUSALITY

Having shown that probability requires causality, we must now more specifically show that the statistical laws are another way of presenting causal laws. It will be remembered that causal laws are so framed as possibilities that when put into application they must always be modified by all the incidental factors which are not excluded. A controlled experiment is an attempt to exclude as far as possible all such incidental factors. This cause corresponds to dominating function, modified in actuality by incidental factors. Causal laws merely state the dominating factors and purposely omit the questions of incidental factors.

In the statistical method no attempt is made to state *a priori* what the cause or dominating function is. A function is chosen, and incidental factors slowly eliminated in favour of it. Given a certain function to examine in its actual operation, experiments are conducted which will give results tabulated in reference to this function. The function is understood throughout not as an abstract legal affair but as a prevailing tendency, which the experiment is supposed to reveal by averages. In such a situation, where it is impossible to eliminate many of the incidental factors, it is clear that the dominating function will be modified in a number of ways, varying according to the presence and interplay of the incidental factors. But it is also clear that the dominating function will, given a sufficient iteration, show itself, whatever it be called, cause or probability. What is being done when an average is struck of these iterations is the ruling out of

incidental factors. In this case they are being ruled out not by abstraction deliberately planned, but by showing that in the long run of instances they do not really count. Thus cause or dominating function is obtained by experimental selective abstraction. A cause is shown to be at work.

We are not denying that the statistical method has great usefulness. Its usefulness is apparent from what we have said above: in any situation where through ignorance or pure difficulty of manipulation it is impossible to isolate cause, the statistical method is helpful. This is the case of thermodynamics and quantum mechanics. It has been found practical in thermodynamics because it is impossible to follow the path of the individual molecule. It has been found practical in quantum mechanics, the study of sub-atomic entities, because not only is it impossible to study the path of these entities, but even their continued identity is questionable.

In practical affairs, for instance in the life insurance business, the statistical method has been useful, because it is impossible for a life insurance company to calculate the tremendously complicated and fantastically modified causes of death. If all the factors affecting the life of every individual could be known and traced at any given moment, the exact risk would be ascertainable. But as it is, the life insurance company can group all these causes into a gross probability. And in so doing they depend upon the uniformity of natural occurrences, and risk only the possibility that these causes will be greatly modified. Thus they depend upon causality for their solvency, and go bankrupt in so far as they depend upon

the random element in nature. All planned human actions depend upon the regularity of occurrences and not upon accidents.

It must be noted that the dominating function exposed by the statistical method approaches but never reaches certainty, only a high probability. Put in another way, it requires an infinite repetition to reach certainty. This is to say that to exhaust all the modifying factors of the actual environment absolutely, an infinite iteration of the experiment would be required. No actual element is ever absolutely isolated from the environment, which is another way of saying that no causal principle can ever be exactly fulfilled in any event. But an infinite number of such events must prove equivalent to the absolute causal principle.

Perhaps an example will make this question of infinity clear. In the throwing of a pair of dice we know that ideally 12 will come up once in every thirty-six throws, since there are thirty-six combinations of all numbers and one combination of 12. This is figuring the situation abstractly. What happens if it is tried out experimentally? In a limited number of throws, say two hundred, this situation will most probably not be borne out. But given a very high number of throws, say 10^6, the ideal relation will be very closely approached. Increase this number of throws indefinitely, and the results will bear out closer and closer to the ideal. But only an infinite number of throws can be expected absolutely to correspond to the ideal of $\frac{1}{36}$. We need no experiment in this case to discover what the dominating function is, since the relation of one combination to all combinations can

be calculated in a minute by means of arithmetic. But in the case of many occurrences this is not always possible.

What, then, does such an ideal statement mean that when a pair of dice is thrown, 12 will come up once in thirty-six times? It means that the dominating function or cause in the situation is this arithmetical relation. When put into application, it means that an incalculable number of incidental factors are influential but that none is invariant.

Causal laws are independent of actuality. But when applied the dominating function or cause is always operative in an actual situation as its invariant. But this function or cause does not show itself as invariant because the situation is modified by all the incidental factors, which, if completely taken into account, would finally have to exhaust the universe. Thus according to the uniformity of nature, strict causality reigns, but does not candidly so appear since we do not know in any actual situation what all the causes of the so-called incidental factors are. Thus the best that can be done is to find the necessary element, and to consider all others as unnecessary or 'chance.' To demonstrate the complete causality of every actual thing, we should have to understand the infinite interrelations of the entire universe. In statistical probability we reach an approximation to the cause of any situation, but cannot reach it absolutely without infinite repetition. In either case we see that in actuality no absolute prediction could be made without having on the one hand infinite knowledge, and on the other infinite time. The remote ideal of the causalistic

method requires infinite knowledge; at any time the remote ideal of the statistical method requires infinite time. The results which the statistical method reaches by mathematical probability are just as causal and abstract as the results reached by the causal method. Both depend upon the logical invariance of functions; neither can be applied exactly to actual prediction, though both approximate it more or less closely.

The whole attempt on the part of recent scientists and positivists of science to declare that causality is not a principle of nature, while admitting that probability is, constitutes a contradiction. It comes about through ignorance of two facts: (1) that causal laws never did attempt to predict actual occurrences absolutely, and (2) that probability requires for its very meaning the goal of certainty, or it has no definition.

PROBABILITY AND LOGIC

We have shown that causal laws are logical conditions, and are better understood as the more inclusive functions of less inclusive functions. With this understanding of the uniformity of nature as an unchanging hierarchy of functions, probability and the statistical method can be reduced to the logical up and down movements of an operator. In Chapter v we defined function as an invariant relation between variables, which is an adequate definition so long as function is being viewed as present in actuality. But in the hierarchy of functions as we present it, the abstraction from actuality has been entirely accomplished, and function is then seen as having

nothing to do with variables, but as being better definable as an invariant relation between invariant relations. Thus a function may be illustrated as one of the rungs in the ladder of the logical series, or perhaps better as one of the concentric circles.

Any actual event, experiment, or demonstration must take place in terms of abstract functions. Any action is a particular consequence of the logical conditions, and may be viewed as a deduction from logical premises. Actions are implications of conditions. The freezing of water by an experimental method is an action; and as such it is compelled to conform to the uniformity of the nature of water, which freezes at zero Centigrade, under ordinary pressures. What, then, defines the freezing point of water is not the method by which it is frozen, but rather the law of its freezing, which determines whatever method is employed. This fact is the reverse of that assumed by Bridgman and the operationalists. A thing is not a thing because of the way in which it acts; rather it acts in a certain way because of its logical nature. A thing is as it acts, not because it acts, but because it is. The necessity is a one-way affair from being to action and not from action to being. Action, which takes place in the temporal order, illustrates and does not constitute the conditions of action. Thus again we see that causality, which is reducible to function, is not a temporal affair, but is constantly being illustrated and exemplified mediately in time.

Given this understanding of action and of the conditions from which action springs, we may illustrate the syllogistic nature of the statistical method.

Perhaps the relation of 1 surface to 6 surfaces of a die is constant;
Certainly these throws (a goodly number) are observed to approach constancy,
Therefore it has not been disproved that constancy exists in this relation.

Something like this is what is done in the experiments by which the statistical method is carried on. It will be noted that the result is a probable conclusion which occupies the same status as the conclusion from the syllogism on p. 150, illustrative of the experimental method from a causal hypothesis.

In *n* experiments an average of $\frac{1}{36} \pm$ was found,
Therefore it may be concluded that the abstract function involved in all instances is $\frac{1}{36}$.

This is a 'law of probability,' inductively discovered in the same manner as a causal law. There is no difference between them, inasmuch as causal laws do not claim absolute invariance in actual demonstration, whereas laws of probability seek in actual demonstration to approach as closely as possible to absolute invariance. Hypothesis, experiment, allowance, or disproof of hypothesis, abandonment, or correction of hypothesis—this is the frank and classical method of discovering laws of causality.

It is difficult to see where the statistical method of probability differs from this. Both conclude with abstract functions formulated as rigidly as possible. The fact that the statistical method ends with a

mathematical formulation of function does not distinguish its results from those of causality. We have shown that cause properly understood is function, and that probability properly understood is cause, and therefore also function. The statistical method is only a roundabout, but perfectly valid, way of following the causal method.

Here, however, we reach an important caution. Statistical results must not be viewed as the final aim of a science. If they are so viewed, the progress of science is hindered and finally stopped. To consider laws of probability as the best that science can accomplish, is the same positivism which asserts that deduction is scientific but induction not, that science is empirical but not rational, that mechanism does not imply purpose and, finally, that the aim of science is directed toward application and practicality rather than toward abstract truth for its own sake.

We have been demonstrating throughout that empiricism is the direction down in the effort of discovering to what extent actuality is logical. There is no such thing as an empirical fact in itself, but a fact is empirical only in relation to a higher system. Such a higher system is itself an empirical fact from the point of view of a still higher system. In the light of this conception, causality and probability appear as one and the same, and the statistical method as both empirical and logical: empirical to the extent to which it refuses to leap to unproved conclusions, logical to the extent to which it seeks to find abstract and invariant conditions of which actuality is only a set of illustrations often

modified. Both causality and probability aid science in its mission of discovering the abstract hierarchy of logical functions, which is the condition of all natural existence in so far as reason is able to understand and control it.

CHAPTER IX

THE FUTURE OF SCIENTIFIC EMPIRICISM

I am come that they might have life: and that they might have it more abundantly.

THE GOSPEL ACCORDING TO ST. JOHN

SUMMARY OF THE ARGUMENT

The revolution in physics has been the occasion for the return to philosophical speculation on the nature of science. This philosophical speculation has become divided into two positions: mentalism and positivism. Of the two, positivism, revamped and refined, threatens to become the orthodox philosophy of science. This preference for the positivistic philosophy is understandable in view of the fact that it seems to fly the banner of empiricism itself. And empiricism is the indispensable bedrock of science, which it would be suicide to abandon. What has happened is that science, through its development, has unwillingly been forced toward a philosophical reconsideration of its own nature. In this reluctant effort, the charm of positivism has been that it seemed to necessitate the least amount of metaphysics and to possess the greatest appeal to hard stubborn facts.

Undoubtedly scientists have been right in holding on to empiricism as the essential of scientific method. But empiricism does not involve positivism. Positivism denies the validity of the speculative reason. Empiricism rightly understood does not deny the speculative reason but rather requires it. Positivism is purely analytical, whereas

empiricism requires both analysis and synthesis. Positivism is application, whereas empiricism requires both theory and application. Positivism would stop the advance of science, whereas empiricism requires continual advance. The proper understanding, then, of what science is depends upon the proper understanding of empiricism. Empiricism is a logical affair, and can be reduced to its syllogistic form.

That empiricism, and *a fortiori* science, should have ever been considered an anti-rational affair, is only to be explained in terms of its historical development. Experimentation was the watchword of those men who broke away from cloistered speculation and unexamined premises. In throwing over sacrosanct premises they believed that they were throwing over the whole of logic in favour of brute facts. Consequently the Renaissance, which witnessed the birth of modern science, came to suppose that the empirical observation of fact and the speculative reason were opposed. The development of science necessarily drew these two threads together in scientific procedure, but did not resolve the anti-intellectual bias of the scientists. Thus the procedure and the philosophy of science were, and still are, at variance.

The preoccupation of scientists with experimentation led them to conclude that science is a description of actuality, and thus that actuality is an absolutely determined affair. But the development of science, in the late nineteenth and twentieth centuries, toward more and more abstract and mathematical formulations, has made scientists realize that there was here no picturable cor-

respondence between their formulations and the world of actuality. In short, the realm of physics represented nothing actual except mathematical symbols on paper. Such a realization has appealed to some interpreters as meaning that scientific formulations are inherently mental, having been formed in the mind and indicating the existence of a mind-stuff, of which actuality is but the appearance. As a check on this wild metaphysical 'explanation,' the positivists have reformulated the older view into what is called operationalism and its similar theories, such as that of logical positivism, which asserts the concepts of science to be merely names for operations performed or performable. This denies objective reality to the objects of science, but does not evade subjectivism, as it attempts to do. It only states subjectivism behaviouristically, that is, it makes scientific concepts dependent upon the mind, and thus unintentionally destroys the basis of empiricism while endeavouring to save it.

Science is neither "the compendious representation of the actual" (the history of actual occurrences) nor thoughts in the minds of scientists or of the race in general. The subject-matter of science turns out to be functions independent of consciousness and therefore non-mental; independent of actuality, and thus non-actual. Functions are the inexorable conditions of knowledge and actuality. The analysis of the scientific subject-matter shows it to be not the content of actuality but conditions abstracted from actuality, conditions which are purely formal. And thus science reaches and strives to make manifest an unchanging hierarchy of functions which is through and through logical. The

whole success and direction of science illustrate that it is dealing with such a formal world, best represented by the least connotative symbols, i.e. those of mathematics. Science is the entire effort of man to acquire knowledge of this abstract world of independent real functions, which are the invariant conditions of existence.

Given this independent subject-matter—the abstract world of independent real functions—induction and deduction may be seen as procedures ascending or descending, in short, as two directions of reasoning. Demonstration, as employed in scientific method, tests an induction by checking its deductive consequences against actuality. The test by consistency is the derivation of that induction from a more inclusive induction as a deductive conclusion. The first is merely allowance; the second is proof. It is to be noted that what is empirical is always the deductive direction down; and the status of items varies in accordance with the direction selected, so that what is empirical from one point of view is theoretical from another.

The whole empirical proof may be understood, regardless of experiment or deduction, as the finding of what is involved in a system. Thus rationalistic and empirical fallacies may be seen as prohibitions against irrelevance, or the jumping from one system to another. When a higher system is dragged in to explain the constituents of a lower (the rationalistic fallacy), the results are contrary to economy or empiricism: that the simplest explanation must suffice. On the other hand, when the constituent parts of a system are employed by themselves as explanations of the system (the empirical fallacy),

the result is too rigid an attempt at economy. Thus the fact that science works mechanistically (down) must not be construed to mean that there is no purpose (up), but only that science is concerned with analysing purpose into its mechanism.

The vastly greater part of scientific attention is devoted to analysis. Induction may take five seconds; deduction twenty years. Induction is a flash, but deductive analysis and checking is a deliberate and often painstaking and long-drawn-out affair. Thus scientists are nearly always directed down, but can only be so because of a prior leap up. The *method* of science is down; the *leading* principle of science is up.

In the light of the abstractive nature of scientific subject-matter, causality is seen not as a determinism of actuality, but as the principle of continuity, whereby the same function is present in different instances of actuality modified by accidental factors. Causality states the invariance of a principle and not the invariance of its practice. Thus in application a causal principle can only be more or less unmodified, i.e. its absoluteness is more or less probable. The formulation of laws of probability does not deny causality but restates it in application. The statistical method examined shows itself to be a roundabout method of abstraction, ending in laws of causality—abstract invariance stated mathematically. What are not invariant are their applications. Thus statistical probability does not in this regard differ from strict causal law.

We have stressed scientific empiricism as the correct method and equated it with deduction, mechanism, and

application. But these presuppose a logically prior direction: higher systems to analyse, theories to be made empirical, probabilities to be rendered invariant, pure science to be some day applied. All this may be summarized in the statement that science accepts no datum or system as final except *pro tem.*, which means that the first postulate of science is the rationality of nature. Empiricism does not dispense with but requires the speculative reason.

SCIENCE MUST BECOME SELF-AWARE

The assumption is held in most scientific quarters that so long as science proceeds with the right method, it does not make any difference to the welfare of science whether scientists abstractly understand what their method is or not. Of course it must be admitted that physics has in the main kept to the correct scientific method. But the fact that it has done so is no warrant that it necessarily always will. How can it be expected to carry on for ever with a method which it does not abstractly understand? Historically, the physical sciences stumbled upon the right procedure, misinterpreting causality as a locked determinism of actuality. This conception did well enough until further discovery showed it to be true only within narrow limits. Thus to-day the old presuppositions of a mechanistic world have proved inadequate, and science is left without a whole-hearted belief in the reality of its subject-matter.

This eventuality has driven it to two errors: unbridled speculation and over-rigid empiricism. The first is represented by wild and meaningless theorizing, the second

by an over-emphasis on experimentation alone. But it is the latter direction in which the scientists are tending. Either would kill the advance of physical science; the first by abandoning empiricism, the second by giving empiricism nothing to operate on. In the latter case, the presupposition that speculation is unscientific, and that the laws of science are nothing more than names for operations, may eventually destroy the very method of empiricism. The absurdity of considering every operation a disparate, unique and particular occurrence would render science nugatory by destroying all its attempts at unification. There would be nothing left but a catalogue of isolated experiments, a history of disconnected events.

The positivism which poses as the true philosophy of science would hinder the future of physical science. But it has already prevented other studies from becoming sciences. Psychology, economics, sociology, and anthropology have all suffered. There being no correct abstract formulation of what scientific presuppositions and methods are, these social studies have endeavoured to follow what they conceived science to be, as exhibited by the physical sciences. The result is that they have swallowed positivism and ignored the implicit but correct method of physical science. In other words, they have already fallen into the same sterile procedure as we predict might happen to physics if it continue on a positivistic basis. The accumulation of uncorrelated data in social studies is already enormous, and indeed perhaps outweighs the data of the physical sciences. But this enormous accumulation has not been synthesized, and in fact now stands in the way of synthesis.

Social studies have never reached the deductive stage, and indeed distrust deduction. This lack alone should indicate that here is no following of physics. The social studies are inductive, but they are inductive mainly at the level of common-sense observation, and thus have never attained any high abstractive level from which deductions could validly be made. The reason that they fight shy of such speculation is their false understanding of empiricism as precluding anything not observable at the level of common sense. Their kind of procedure might go on for ever, piling up generalized observations, without leading to one significant generalization which could throw light on new and unsuspected facts, and thus open up a fruitful field of inquiry. The most developed of the social studies are economics and psychology, which have to some extent looked for invariant and abstractive conditions. But even they have been hopelessly confused, and have failed to obtain anything solid enough for agreement, by their failure to understand the nature of scientific empiricism, which they persistently misread as a prohibition against the drawing of conclusions.

The failure to understand explicitly what science is has not yet proved crucial to the physical sciences. But it may, and certainly will, if this condition is allowed to continue and science persists in its positivistic misinterpretation. What is a danger to the physical sciences is already a disaster to the social sciences. The need for the abstract formulation of science is of the utmost importance to all science.

RELATION BETWEEN SCIENCE AND SOCIETY

So much for the correct understanding of science as it affects science itself. Science as an active institution, however, is not an isolated affair. It is an integral part of society. Science is one social institution among many, and it demonstrably affects and is affected by all others. It cannot thus go on for ever in Olympian isolation, but requires integration with society as a whole. Therefore it can readily be seen that the correct understanding of science by society is of the utmost importance for science and for society.

What does science require of society? Science requires that society support it and at the same time leave it free to develop as it sees best. What does society require of science? Society requires that science produce miracles in the shape of tangible results having practical application. So long as science furnishes these, it will be supported and lauded and left free. But if it should fail to rain benefits immediately understandable as such, there is always the danger that the public will become impatient of mere theory and withdraw its support. There is a paradox in all this, that if science deliberately sets about to produce practical results, it will not continue to produce them. Practical results do not follow from previous practical results but are the by-products of development in speculative theory. Thus science is being most practical for society when it is considering practicality the least.

The danger of the positivistic understanding of science on the part of non-scientists can be readily seen. Society will not wait patiently upon science but insists upon

directing its course toward practical application. It does not want theory, it wants results; and will not give money for the benefit of abstract speculators, although it will give millions for laboratories. But of course without theory practicality is an impossibility. Unquestionably, if the pressure of popular positivism is exerted on the scientists, the results must be disastrous regardless of whether scientists themselves concur in such a philosophy.

But if, on the contrary, society could form some understanding of what science is, of what it is engaged in doing, and of what it hopes to do, it would be realized that the greatest practicality to society lies in pure science. Society would cease its importunings for quick results. It would then be content to support science and leave it free to follow its own development.

The relation between science and society involves far more than the question of whether science will be allowed to develop unimpeded. It involves the question of whether society will itself be allowed to develop. No one will dispute the great social benefits which are attributable to science. The whole stage of development of modern civilization can be laid directly or indirectly to the physical scientists. It is a platitude to assert that the modern standard of living depends upon technological proficiency; and modern technology, of course, is a by-product of the physical sciences. Its tremendous acceleration has paralleled the acceleration of physical science. There are also great benefits which have accrued from the biological sciences. The technology of medical practice: hygiene, immunization, etc., are by-products of the biological sciences. It is not too much to assert that

the whole superiority of the present day over the eighteenth century is almost entirely due to the progress of the physical and biological sciences.

But meanwhile what has happened in the field of social relations? Have we any such improvement over the eighteenth century, or is there perhaps a retrogression? It is rather the latter. The contradiction has developed in the last few decades that the greater the advance in technology, the greater the disaster in social life. Every time a labour-saving device is invented, and greater efficiency achieved, it means that more labourers starve, and thus a decrease in consumption follows an increase in productivity.[1] As another example of what happens when the sciences do not advance together and one science runs wild, we have technology producing equally 'beautiful work' in medicine and chemical warfare. Without social science to guide technological chemistry, its applications may often cancel each other. Without social science to decide, we have only the vague normative judgment of good or bad, which is neither sufficient nor authoritative.

This chaos in social relations has not been alleviated by the social sciences, in spite of their pretensions. In other words, social science has shown no such advance in understanding as has physical science. Now we must note that physical science was the occasion for the dislocation of social relations, as well as for the advance of technology. In fact, the advance in technology has occa-

[1] This is definitely true of capitalist society, but, logically speaking, need not be true of communist society, where a technological advance should result in an advance along the whole front of society.

sioned the dislocation of social relations, in the absence of any exact knowledge or ability properly to organize them in accordance with technological advance. If this dislocation be permitted to go much further, the advance in physical science will destroy the organization of society which makes science possible. Thus by its very merit, physical science may cut its own throat.

The question reduces to this. There is a race in progress between science and society. Will society understand science soon enough to allow science to develop a science of society by which both science and society can be saved?

The conclusion which develops from a consideration of the interrelation of science and society is that the development of every science is dependent upon the development of every other science. The rapid advance of any given science therefore forces the necessity for the rapid advance of every other science. Otherwise one science developing too rapidly will end by destroying society, and therefore put an end to its own development as well. It is one thing to have a leader, but quite another to have that leader so far ahead of the main body that he cannot any longer be followed. As a result, the army fails to hold the advance it had already made, and falls into chaos, whereas the leader is cut off from his support and perishes.

Physical science has now forced the necessity for the development of social science, and this is imperative lest all science perish from contemporary society. If it be suspected that we are making wild and abstract predictions based on pure speculation, and that there is no

observable immediate danger of any such eventuality, we have only to call attention to what is happening to-day in Germany, where an anti-liberal and reactionary social order gives no support and has no tolerance for anything not immediately useful to its narrow purposes. German society has failed to keep up with the standard set by German science, and has therefore discontinued German science. There is a deadly logic involved between the given stage of a social order and the given stage of science. Though some small leeway may be allowed, their ability to separate is definitely confined within certain limits. Therefore the understanding of science on the part of a society is requisite for both science and society.

IS SOCIAL SCIENCE POSSIBLE?

We have pointed the extreme snd urgent need for social science. Two objections will be made to this. The first will state that social science is already in process of development, and that it must be given enough time to become an adult science. The second will state that social studies can never become sciences on which to base predictions sufficient to guide society. Let us answer these objections. To the first we may reply that, as already indicated, a continuation of the present methods in social science will never yield an exact science because abstract and independent laws are not being sought, and will never be sought so long as social scientists misunderstand scientific empiricism. Social science is not a young science, but has been before the public as an organized affair nearly as long as chemistry. Moreover,

during the time it has been promoted as a science, it has shown no signs of development. The development of a science is not a function of time but of the understanding of method.

The second objection will require more consideration. There is a widespread conviction that a sharp break exists between the physical and the social sciences, and that the same method cannot prevail in both branches. This conviction has been given categorical authority in German philosophy, which distinguishes between *naturwissenschaften* and *geisteswissenschaften*—the mathematical natural sciences and the normative social sciences. What is implied, of course, is that exact mathematical measurement applicable to physical subject-matter has of necessity no applicability to social subject-matter. If this were true it would have to be granted that social relations could never be made the basis for an exact science, and therefore never broadly applicable to the guidance of society.

The division between the subject-matter of physical science and the subject-matter of social science, naming the former empirical and the latter normative, assumes a fallacy which we have exposed above.[2] No subject-matter considered by itself can properly be labelled empirical or normative. It has been shown that the same subject-matter which is normative from one level is empirical from another, just as purpose analyses into mechanism and mechanism synthesizes into purpose. There is no *a priori* principle which forbids the treatment of values in social relations from being the subject-matter for empirical analysis, and from being analysed

[2] See p. 158 ff. for mechanism and purpose.

into their mechanisms, exactly as is done with the physical subject-matter.

Value-judgments do not have to be regarded as unanalysable and as merely normative. For instance, biology might have taken the arbitrary position that the quality of livingness is a value primitive and irreducible, and as such not subject to analysis or measurement. Certainly it is a value, but this does not prevent biology from analysing this value into its mechanisms, without the need of introducing the value as an element in its analysis. Similarly, the analysis of the values involved in social relations must be for the uses of science *wertfreiheit*. Thus the fact that social relations are themselves values does not mean that as values they cannot be scientifically treated. They can be subjected to isolation, on which induction, deduction, and experimental verification are brought into play, until a sufficient deductive system is formulated which allows of mathematical treatment.

We are unimpressed by the argument that social science is for ever precluded from the same procedure and therefore from the same measure of success that physical science enjoys. The proponents of this theory offer no argument in defence of their position. They seem to have taken the failure of social science and made it causal: because there has been no social science, there can be no social science. To erect a failure into a necessity is orthodox positivism. The door to science must be left open. That anything is more than likely to be discovered, is the true scientific attitude. Social science is a definite possibility.

THE FUTURE OF APPLIED SCIENCE

Science, like all rational endeavour, is directed toward the future. What has already been accomplished in its short past may be taken as the merest hint of what is to follow. Theoretical scientific formulations will be utilized for practical purposes in the future to a much greater extent than they are at present, even though such practicality is not at the moment envisaged.

The future of applied science is not to be conceived merely in terms of great improvements along lines already laid down by present inventions. It does not mean only faster airplanes, better air-conditioning, lighter metals of greater tensile strength, etc. Nor must the advance of applied science be conceived narrowly in terms of mechanical technology and the saving of factory labour, although this is one of its services. The application of science must be understood more comprehensively in terms of the annihilation of the limitations of time and space, which is only another way of saying the saving of energy. What has formerly been conceived to be the 'natural' and hence inevitable way of achieving material ends is shown by science to be a wasteful and often roundabout method. Many years ago no one would have dreamed that the production of agricultural products could have been indefinitely improved and accelerated. They rather depended on 'nature.' But now, by the greater understanding of nature, its processes have been speeded up and made more efficient. For instance, the 'ageing' of spirituous liquors may be accomplished speedily. 'Napoleon' brandy, being a function of the

action of enzymes and not of Napoleon, will be made overnight. It is not too much to predict that advance in biology will make the sowing of vast acres for a small yield unnecessary, and the same yield will be obtainable on a small patch controlled and not subjected to the accidents of weather.

Since time immemorial, men have kept animals for their milk, meat, hides, and hair, and this has necessitated the slavery that goes with a parasitic existence. For the nomad practically lives like a parasite on cattle, and must therefore follow the cattle's way of life. But applied science, no less than theoretical science, abstracts to dominant functions. Technology poses the question of how much can be left out in the solution of any given practical problem. If we want only meat, hair, hides, and milk from cattle, why go to all the trouble of having to take care of herds? If we expect the action of enzymes, why wait on 'time'? Why not merely manufacture items where it is more economical? Mr. George W. Gray points out[3] that given the wholesale manufacture of the Lindbergh perfusion pump and, given the technique of keeping organs alive outside the organism *in vitro* perfected by Dr. Carrel, it requires no great imagination to suggest the picture of bovine mammary glands kept to perform their function—udders without cows—and such products as insulin produced by merely keeping part of the pancreatic gland rather than whole sheep to be butchered.

But this is a timid and half-way presentation. Science abstracts from abstractions. And applied science will

[3] *Harper's Magazine* for February 1936.

finally abstract from even the secretion of glands to the manufacture of the essential substances. Certainly milk and insulin will be synthesized in the laboratory without the useless cultivation of waste by-products. Moreover, technology need not copy the so-called natural product; it can make better milk and better insulin than the glands.

What the practical results of a true social science would be staggers the imagination. If the world has wasted time and energy on material problems because of its ignorance of natural science, what was and still is its plight in wasted time and energy in social endeavour? Wars, revolutions, and social conflicts generally would be resolved by a proper social science. The hit-or-miss political blundering which goes on unaltered from ancient times would at last change into something rational and planned. This does not mean, of course, that at any stage of advance an effortless utopia or a heaven-on-earth can be achieved. It does mean the resolution of those importunate problems which have held down human energy by demanding the most of it. This energy would be released not for a silly leisure of amusement and boredom but for the attacking of problems at a higher level. To paraphrase Plato, the purpose of applied science is not to create mere material riches (though these have their place) and the furtherance of life for its own sake, but to set men free for the pursuit of the good life.

THE FUTURE OF THEORETICAL SCIENCE

The marvels of applied science are not, however, the whole story of science nor even its leading purpose. Unfortunately, the public has no comprehension of

science other than in its practical capacity. Thus, as H. G. Wells says, to most persons science is alchemy. The applications are the merest by-products of the great domain of science, which is once and for all concerned with the truth, and which must hew to that line and let the chips fall where they may. In this domain of science there are many yeomen who only stand and apply the technique, but the real advance of science is due to a few leaders who are entirely occupied with carrying forward the theoretical aspects of science.

The advance of science has been directed in the past toward greater specialization within sciences. Chemistry has split up, for instance, into physico- and bio-chemistry, biology into a score of special branches, each of which goes as a separate science. But the advanced science of physics begins to manifest another direction besides this one. The second movement is toward unification of branches previously considered disconnected. For instance, astronomy and physics have become one science, and the attempt is being made to discover a unified field theory which will subsume relativity and the quantum. The advance of science should move in these two directions: toward greater and greater analysis, and thus specialization, and toward greater and greater synthesis, and thus generalization.

But the movement toward synthesis in the separate sciences is not enough. What is required is a synthesis which will be capable of embracing all the sciences already known and those to be known under one grand science. Such a general science of sciences would have to show each science as a special case of its universal laws,

and thus exhibited the continuity between chemistry and biology, biology and psychology, psychology and sociology, etc. Its laws would have to be of a generality such that the laws of all separate sciences could be deduced as special cases, and yet not be superseded by the more general.

With the development of science, a greater and greater rationality is required. But this does not mean a greater and greater mentality. In other words, men will not have to be born with greater cerebral capacity, either quantitative or qualitative. The advance of the race depends upon the discovery of ideas and not upon an advance in innate psychological capacity. A fairly stupid man, by using trigonometric tables, can accomplish what a great intellect would be unable to accomplish without them. We have shown that as a science advances it relies less and less upon flashes of genius and more and more upon a solid deductive background. Were it not for this fact, we might indeed look with dismay at the future of science, and *a fortiori* at the future of the human race. But with this understanding it may be seen that if all sciences advance together, their acceleration may increase indefinitely—and this without a corresponding increase in innate mental capacity. The fact that each stage of scientific advance can start from the accumulated body of knowledge, and does not have to start from scratch, takes science out of the mentalistic psychological category, and even in the last analysis out of its reliance upon genius.

We have already enunciated and subscribed to the principle of *wertfreiheit*, according to which science is

free from values. But this does not mean that it does not start from values and emerge with them. It resolves values into rational equivalents, whereby newer values are allowed to be actualized. It is by virtue of the fact that science proceeds rationally and not affectively, that it is able to obtain new values. The achievement of values is not obtained through the envisagement of values but through scientific rationality which is value-free.

The whole advance of reasoning may be said to have been this very reduction of that which was first normative to that which later became empirical. And thereby more and higher normative problems are perceived. The savage who sees the whole environment as normative—friendly or unfriendly—is not able to manipulate it, i.e. to increase its 'friendliness'; and thus he is precluded from envisaging higher values. To-day when we look to the good intentions of rulers rather than to scientific systems of government, and indignantly punish criminality, we are in the plight of the savage: we have not reduced these normatives to empiricals.

A similar reduction in the affective has taken place in some sciences: 'spirits' to 'properties' and 'properties' to pictorial entities, and finally pictorial entities to mathematical symbols. From the affective to the mathematical is the true direction of science. This is only another way of stating that the direction of all reasoning is from the normative to the empirical.

The hope of the human race rests upon the development of science, which will discover for it values immediately useful and practical, and intrinsic values, to be appreciated far beyond anything that may have

already been indicated. But hope and longing, and the attainment of immediate application, will not by themselves accomplish anything. All depends upon the understanding and allowed procedure of strict scientific empiricism.

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